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Pollution attenuation by roadside greenbelt in and around urban areas

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ABSTRACT

Greenbelts are effective tools for mitigation of traffic induced air and noise pollution. In this study, the potential role of greenbelts along the roadside for the reduction of air pollution and noise levels has been assessed by using seasonally monitored data in a megacity of Bangladesh. Correlation analysis was performed between the vegetation status, measured by canopy density and shelterbelt porosity, and the total suspended particles (TSP) removal percentage. Further, the reduction of noise level was also analyzed. The results showed that the greenbelts greatly contributed to reduce TSP pollution and it was as much as 65%. Noise level reduction was also achieved up to 17 dB when compared to the open area. Moreover, TSP removal percentage was correlated to the crown density. Area having higher crown density demonstrated less air pollution and lower level of noise compared to the area having lower crown density. Greenbelt showed better performance in summer time than winter.

Introduction

During the past few decades, urban areas have experienced increasing environmental stress, notably in the form of poor air quality, excessive noise and traffic congestion. Climate change impact has also added more stress. Road traffic is considered as one of the most important sources of air and noise pollution with adverse effects on human health (Aparicio-Ramon and Surez, 1993; Lercher, 1995; Williams and McCreae, 1995). Studies indicate that nature provides restorative experiences that affect people's psychological well-being and health in a positive way (Kaplan and Kaplan, 1989; Ulrich et al., 1991; Hartig et al., 2003; Herzog et al., 1997). There are also indications that green plants act as a buffer or moderator of adverse conditions (Wells and Evans, 2003). To abate the impact of pollutants, environmentalists and decision makers have long been emphasizing the need for a "perennial green envelop" in and around urban areas as well as along roadsides (Kapoor and Gupta, 1984, 1992; Chaulya et al., 2001; Rao et al., 2004).

Greenbelts along the traffic streets are not only used for the beautification of a city but also to ameliorate the environment in the street canyon. In addition to ecological benefits, green plants balance the local meteorological condition by controlling the temperature and moisture as well as improve the urban substance metabolism by adsorbing the poisonous gas and dust and by reducing the noise level (Yang et al., 2008). The direct absorption of gaseous pollutants occurs through leaf stomata and water soluble pollutants are dissolved onto moist leaf surfaces (Nowak, 1994). Filtering capacity of greenbelts increases with more leaf area, and is thus higher for trees than bushes or grassland (Givoni, 1991). The capacity is also greater in evergreen trees because the leaves are not shed during the winter, when the air quality is usually worst due to dry weather. Trees also help to modify the local climate by lowering the air temperature through direct shading and evapotranspiration. The reduced air temperature can slow down the atmospheric chemical reactions, which produce secondary air pollutants in urban areas (Taha, 1996; Nowak et al., 2000). Thick vegetation may simply cause turbulence in the air while a thinner cover may let the air through and filter it (Bernatzky, 1983). In urban areas trees can also be used as buffers which are able to reduce a significant amount of noise (Huddart, 1990). Plant leaf absorbs energy by transferring the kinetic energy of the vibrating air molecule in a sound field to the vibration pattern of the leaves (Pathak et al., 2008). Thus, the role of vegetation belts in the attenuation of road traffic air pollution (Zhang et al., 1997; Beckett et al., 1998; Nowak et al., 2006) and noise (Erying, 1946; Embleton, 1963; Aylor, 1972; Martens and Micheisen, 1981; Fang and Ling, 2003) has gained much attention around the world in recent years.

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The efficiency of vegetation in reducing the air and noise pollution depends on many factors including the local condition (Svensson and Eliasson, 1997), the degree of pollution and vegetation coverage. An important factor in developing vegetation belts is that different plant species have a varying degree of sensitivity toward different stressors.

Traffic is the major source of noise and air pollution in many cities, including the study city – Khulna of Bangladesh. The present investigation evaluates the performance of greenbelts toward air and noise pollution by analyzing the correlation between seasonally monitored data of TSP from green belts along two streets (in and around) of Khulna Metropolitan City of Bangladesh and the vegetation status measured by the canopy density and the greenbelt porosity, and measuring the noise level reduction.

Materials and methods

Location

A street (4 lanes) with 7 m wide greenbelts on both sides was selected in Khulna City, Bangladesh. Another road was selected just outside the city (Khulna-Batiaghata Road) having similar width of greenbelt. These two sites were selected as the study area. Bus, truck, private car, three wheeled vehicle like auto rickshaw and human-powered van and rickshaw, etc. are the common mode of transportation on these roads. Ten sample plots from each site were marked considering locations either enclosing open spaces or low buildings (up to three story) to avoid the influence of high buildings along the road on the vertical distribution of the trees. Tree species and number of each type are described in Table 1. Some unidentified herbs and shrubs were also present in the sample plots.

Characterization of vegetation growth in sample site

To characterize the shape and growth status of vegetation stands, crown density and shelterbelt porosity were measured. Crown density was measured by a crown densitometer (Convex Model A) at the center of the plot at all directions. The convex shaped desiometer having a cross shaped grid with 24 quarter inch squares help to measure the percent of overhead area not occupied by canopy through only the sky in reflection. The difference between this and 100 is an estimation of overstory density in percent. The larger the crown density is, the denser the vegetation structure will be. Shelterbelt porosity is the ratio of perforated area to the total surface area exposed to the wind. The smaller the shelterbelt porosity, the denser the vegetation structure and this was measured by digital photos in the sample sites and then calculated by using the digital image processing method. It was done by flagging a wrap around the shelterbelt near breast height with a color that contrast with the shelterbelt and showed up clearly on the photo. Once the flagging was in place, the vertical distance from the base of the tree to the flagging was measured and photo was taken. The detail of the method was described by Xie et al. (2002).

Collection and measurement of total suspended particles

Total suspended particles (TSP) was collected during a sunny day without wind or with a gentle breeze from 10:00 a.m. to 3:00 p.m. when the traffic flow was observed fairly stable. TSP collection was carried out three times per season (winter and summer). The mini volume portable air sampler (Airmetrics Co, Inc.) at 5 L/min was used to measure TSP at 1 m height from the ground level. Suspended particles were collected on Pure Teflon filters, Whatman (37 mm diameter, 2 μm pore size) and Pure Quartz, Whatman (37 mm diameter) filter paper. In both the study sites, four sample readings were recorded at the distance of 0, 2.5, 5 and 7 m away from the roadside in both directions. An open space without any vegetation in each site was chosen as negative control. Following the collection of TSP, the bag was sealed and weighted immediately. Thus, humidity did not affect the results. Samples were collected in replicate every time including controls and the mean values were taken into account. The TSP removal efficiency by the greenbelts at each site was calculated by using the following formula –

$$P = \frac{C_s - C_n}{C_s} \times 100\% \quad (1)$$

where C_s = TSP concentration at the roadside. C_n = TSP concentration at the endpoint of greenbelts.

The relative effect of trees in reducing local TSP pollution concentrations was calculated from the amount of pollution removed by trees by using the following formula (Nowak et al., 1998):

$$E = \frac{R}{(R + A)} \quad (2)$$

where, E = relative reduction effect (%); R = amount removed by trees (kg); A = amount of pollution in the atmosphere (kg).

Measurement of noise reduction

Between the two sites, City Street experiences more number of vehicles compared to the Khulna-Batiaghata road. In case of City Street, there were 7 different types of tree species with 55 ± 5 number of individuals per 20 m length of the road. In the second case, there were 9 different species with 61 ± 6 numbers of individuals per 20 m length. In both the cases, the strip of plantation had 7 ± 0.5 m width. Noise levels were measured at similar environmental and physical conditions of the trees during 2.00–4.00 a.m. at night to avoid the noise of other sources which will affect the measurement. A water motor pump as a noise source was used with a noise level of 100.3 dB(A) and measurements were carried out with a digital sonometer (Chauvin-Arnoux CA 832) at 1.20 m height from the ground level. Measurement was done beyond the 7 m width of the greenbelt. There was no elevation difference between noise source and sonometer. Both of the areas were approximately flat and free from steeply sloping. The noise level was also measured in an open area (no green belts), which had the same topographic features of the two study sites. All measurements were done in replicate and the mean values were used in the analysis.

Results and discussion

Seasonal crown density and shelterbelt porosity of vegetation are presented in Table 2. The maximum height of the trees in the selected greenbelts was 7 (±0.5) m. Summer crown density in the study area was rather higher and shelterbelt porosity was lower, whereas both of them were to the contrary in winter. This was related to the leaf shedding tendency of plants during winter.

TSP removal

The TSP removal percentage in Khulna City Street and Khulna-Batiaghata Road is presented in Fig. 1. The TSP removal percentage showed a tendency to increase by greenbelts and the further away from the street, the higher TSP removal percentage is. Zhong et al. (2001) reported that TSP concentration was higher near the roadside and the vertical distribution of TSP concentration under the crown is relatively equal. Therefore, particulate matters were first barred and held up by the short and dense shrubs at the front 5 m of the greenbelt. At the furthest 5 m away from the street, particulate matters were reduced to a lower level. Thus, the width of the greenbelts should not be less than 5 m along the street. It is better to plant both shrubs and large trees with a gradient of shrubs in the

Table 1
Identification and the average number of tree species counted within the area of 20 × 7 m^2 at each study site.

Study area	Species	Family	No. of trees
Khulna City Street	*Acacia nilotica* L.	Leguminosae	16
	Acacia aurifuliformis A. Cunn. Ex. Benth.	Leguminosae	6
	Albizia lebbeck L.	Leguminosae	5
	Dalbergia sissoo Roxb.	Fabaceae	9
	Cocos nucifera L.	Palmae	7
	Ziziphus mauritiana Lamk.	Rhamnaceae	4
	Swietenia mahagoni (L) Jacq.	Meliaceae	8
Khulna-Batiaghata Road	*Phoenix sylvestris* Roxb.	Palmae	14
	Acacia nilotica L.	Leguminosae	12
	Bombax ceiba L.	Bombacaceae	8
	Acacia aurifuliformis A. Cunn. Ex. Benth.	Leguminosae	7
	Albizia lebbeck L.	Leguminosae	3
	Melia azedarach L.	Meliaceae	6
	Moringa oleifera Lamk.	Moringaceae	6
	Eucalyptus camaldulensis Dehnh.	Myrtaceae	3
	Cocos nucifera L.	Palmae	2

Table 2
Crown density and shelterbelt porosity of vegetation in summer and winter.

	Season	Khulna City Street	Khulna-Batiaghata Road
Crown density (%)	Summer	63 ± 4	85 ± 3
	Winter	51 ± 3	79 ± 4
Shelterbelt porosity (%)	Summer	36 ± 4	4 ± 2
	Winter	44 ± 4	26 ± 3

front and then large trees, which has the optimal efficiency on TSP purification from shrubs and large trees. Among the two seasons, the highest TSP removal occurred in summer when leaves of trees were fully expanded and the concentration of pollutants was high. The reliability of the estimate was evaluated by comparing it to values reported in other studies (Yang et al., 2008). The flourished leaves and branches as well as the greenbelt structure with small and large trees were able to slow down the airflow as well as to trap the particulate matters (Coceal and Belcher, 2005). Therefore, more evergreen vegetations should be planted in the roadside greenbelts in order to improve the removal efficiency during winter time.

The maximum TSP removal was recorded as much as 65% during summer time along the Khulna-Batiaghata road. With this removal efficiency result the benefits of urban road-side trees have been calculated as the relative reduction effect as much as 0.4%. Similar result was reported by McPherson et al. (1994) who calculated that the trees of Chicago improved air quality by 0.4% (2.1% in heavily wooded areas) in the process of particulate matter reduction. The purification efficiency in Khulna-Batiaghata road was higher than the Khulna City Street. This might be because of the vegetation structure and growth difference between the study areas. The linear regression suited best fit for positive correlation between TSP removal percentage and crown density (R^2 = 0.73) and negative correlation between TSP removal percentage and shelterbelt porosity (R^2 = 0.81) (Fig. 2). The regression analysis implies that the larger the canopy density is, the more noticeable the TSP purification efficiency will be. When the shelterbelt porosity was below 20%, the TSP removal percentage almost kept stable at the same level and the TSP removal percentage decreased highly when the porosity is higher than 40%. Thus the shelterbelt porosity range at 20–40% can be defined as the optimum for TSP removal. The findings of this study thus show that the better purification effects will be achieved with the result of the more vegetation plantation as well as the type and characteristics of tress. However, too dense configuration of the vegetation would make turbulence in air during vehicle movement and will decline the greenbelt health.

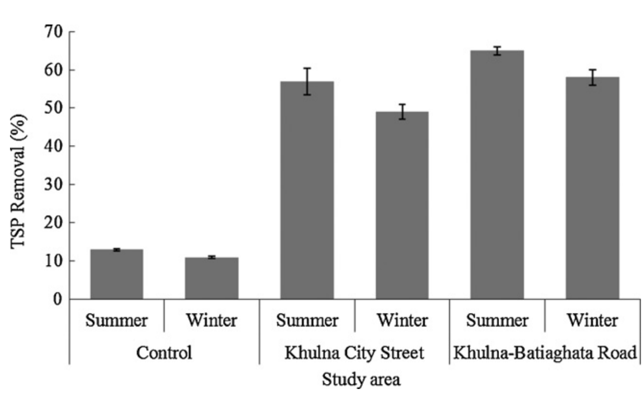

Fig. 1. Average removal of total suspended particles (TSP) from air by roadside shelterbelts along two streets in Khulna City, Bangladesh during summer and winter (mean ± SD).

Noise reduction

Noise from Traffic and other sources creates health problems for people in urban areas. Noise pollution is a customary problem along the main roads of different cities in Bangladesh. It is possible to reduce a considerable amount of noise by providing sufficient surface areas with suitable plant species and forms. Compared to the control value in open area, greenbelts in Khulna-Batiaghata road reduced noise by 17 dB(A) more while in Khulna City street this reduction value was seen 13 dB(A) (Fig. 3). In a similar study, Pathak et al. (2008) also found the maximum attenuation of 17 dB for *Putranjiva roxburgi* and 14 dB for *Cestrum nocturnum* at higher frequency range. The characteristics of trees, i.e., crown width, height, number of branches, types of leaves, position of the leaves against the direction of noise, and density of plants affects the reduction of noise (Bernatzky, 1978; Finke, 1980). This was may be due to the presence of denser vegetation in Khulna-Batiaghata road compared to Khulna City Street which reduced the noise more in Khulna-Batiaghata road. Greenbelts reduce noise through various means viz. absorption by leaves, dispersion, reflection and diffraction by stems and spherical divergence by canopy (Wiener and Keast, 1959;

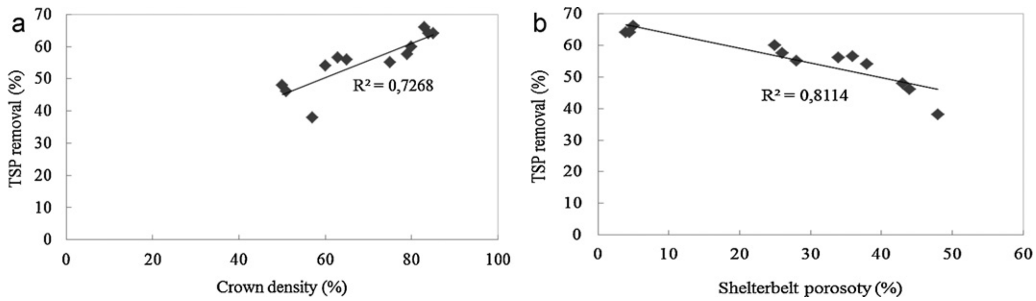

Fig. 2. Regression analysis between (a) TSP removal percentage and crown density; and (b) TSP removal percentage and shelterbelt porosity.

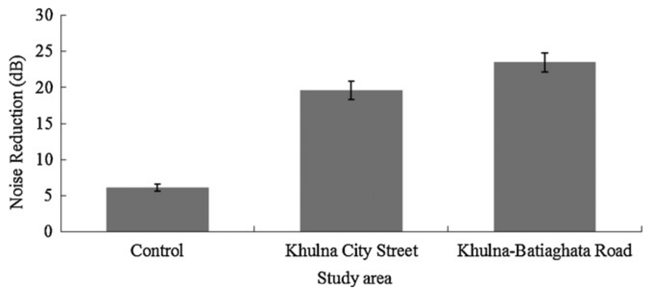

Fig. 3. Average traffic induced noise reduction by the roadside greenbelts along two streets in Khulna City, Bangladesh (mean ± SD).

Cook and Haverbeke, 1974; Martens and Micheisen, 1981). Wider greenbelt provides greater surface area and therefore more opportunities for diffusion and absorption of noise (Cook and Haverbeke, 1974) resulting greater reduction.

Conclusion

Through pollution removal and other tree functions, urban green belts can help to improve the environmental quality and consequently improve human health. This study evaluated that the road-side vegetation stands can play an important role in the reduction of traffic induced air pollution (in terms of TSP removal) and noise levels in and around urban area. The TSP removal percentage is positively correlated with the canopy density and negatively with the shelterbelt porosity. A significant amount of noise was also found to be consumed by the green belt. Therefore, we conclude that further research is required at large scale to quantify accurately which species is suitable to trap more particulate matter effectively and to identify the practical measures by which air pollutants removal by trees can be maximized.

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