Review Article

Air pollution and public health in developing countries: Is Sri Lanka different?

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Abstract

Indoor and outdoor air pollution is a major public health challenge in developing countries and much concern has been raised among policy makers, public health experts, clinicians, and the general public in recent years. A spectrum of health outcomes has been shown to be associated with exposure to air pollution in epidemiological studies and by laboratory investigations. It is estimated that indoor air pollution resulting from exposure to solid fuel accounts for over 1.5 million premature deaths and 38.5 million Disability-Adjusted Life Years. Globally, it is estimated that outdoor air pollution accounts for over 800,000 premature deaths and 6.4 million years of life lost; of these numbers, 65% is from Asia alone. There is emerging evidence that the actual burden is much larger than the estimated values. The World Health Organization has estimated the number of deaths attributable to indoor air pollution and outdoor air pollution in Sri Lanka to be 4200 and 1000 deaths, respectively. Although country information is limited, a few epidemiological studies gives us the opportunity to understand and compare the Sri Lankan situation *vis a vis* other countries. This includes the 16 epidemiological studies identified by a scientific review in 2010 and several other published studies and preliminary data from ongoing studies.

Keywords: Air pollution, economic costs, health outcomes

Introduction

Air is a complex mixture of many components. Nitrogen and oxygen constitute approximately 99% of the mixture with the remainder being made up many constituents in trace quantities. The United States Environmental Protection Agency (USEPA) defines an air pollutant as "a substance in the air that, in high enough concentrations, produces a detrimental environmental effect" [1]. USEPA further states that "these effects can be either health effects or welfare effects. A pollutant can affect the health of humans, as well as the health of plants and animals".

The first indications of adverse effects of air pollution on health were noted from the marked increases in mortality following episodes of severe air pollution. For example, the great smog of '52 in London that lasted from 5th to 9th of December, 1952, trapped coal smoke in the Thames valley under favourable climatic conditions and is estimated to have resulted in 4000 premature deaths, and 100,000 more were made ill for weeks afterward. In the last 2-3 decades, epidemiological studies conducted in many parts of the world have uncovered a series of health consequences associated with exposure to air pollution. In parallel, a better understanding of the underlying biological mechanisms of such effects has also evolved.

Biological mechanisms

Many pollutants act together in a series of partly inter-related biological mechanisms which result in a range of adverse health outcomes. The biological mechanisms include triggering of oxidative stress, stimulation of both local and systemic inflammation, reduction of muco-ciliary clearance in the respiratory tract, increased reactivity of the respiratory epithelium, reduction of the macrophage response to microorganism invasion, increase of epithelial permeability and adhesion to microorganisms, bronchial irritation, autonomic imbalance, pro-coagulant activity, lipoperoxidation and atherosclerosis, reduction of O_2 delivery to key organs and the developing foetus etc. [2-4]. These actions can be different based on the type of pollutant and strength of exposure [5,6]. Several studies on human beings and in animal models have proven the biological mechanisms[7-11].

Vulnerable groups

Subclinical effects of air pollution, such as temporary deficits in lung function or pulmonary inflammation, may occur in most of those exposed while mortality may occur in a few. It is usually the more susceptible who suffer from more severe effects. Several population groups are more vulnerable to the effects of air pollutants, such as, those who are innately more susceptible to the effects of air pollutants than others, those who become more susceptible as a result of environmental, social and personal behaviors, and those who are simply exposed to unusually large amounts of air pollutants [12]. These population groups include unborn and young children, pregnant mothers, elderly people, those with cardio-respiratory diseases, those who are

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exposed to other toxic materials that add to, or interact with, air pollutants, and the socio-economically deprived [12]. For example, IAP disproportionately affects children's health due to their physiological susceptibility as a result of their growth and spending more time indoors where pollutant levels may far exceed those recommended by the WHO during cooking and immediately afterwards[13].

Burden of air pollution
Currently, the assessment of the burden of air pollution is based on selected health outcomes that have been associated with air pollution with definitive evidence; there is also a spectrum of health conditions that are not considered in this estimation but are suggestive of being adverse health effects due to air pollution. Hence, what is being estimated may only be the tip of the iceberg, representing a small fraction of all adverse effects due to air pollution. High frequencies of less severe effects may lead to more severe chronic effects in later life or with greater exposure.

a. Indoor air pollution
Indoor air pollution (IAP) from combustion of solid fuels for cooking and space heating is one of the ten most important risk factors contributing to the global burden of disease. It is estimated to account for over 1.5 million premature deaths and 38.5 million Disability-Adjusted Life Years (DALYs)[14]. The World Health Organization (WHO) estimated that the number of deaths attributable to IAP in Sri Lanka in 2004 was 4300[15].

Secondhand smoke (SHS) is a common source of IAP in both the developed and the developing world. Worldwide, about 40% of children are exposed to SHS and an estimated 165,000 children under 5 die each year of lower respiratory tract infections caused by exposure to SHS [16]. The largest burden of DALYs due to SHS exposure is from children[16].

According to the Global Youth Tobacco Survey of 2007, 65.9 % (95% CI, 62.1 - 69.5) of Sri Lankan school children (aged 13 – 15 years) reported that they have been exposed to SHS in public places. In surveys conducted in 2003 and in 1999, 68.3 % (95% CI, 64.9%–71.4%) and 67.9 % (95% CI, 64.5%–71.2%), respectively, reported exposure to SHS[17].

b. Outdoor air pollution
Outdoor air pollution is responsible for about 800,000 premature deaths and 6.4 million years of life lost. This burden occurs predominantly in developing countries with 65% being in Asia[18]. About 81% of deaths and 49% of DALYs in people aged > 60 years are attributable to the adverse effects of outdoor air pollution. Children under 5 accounted for 3% of deaths and 12% of DALYs attributable to outdoor air pollution [19]. WHO has estimated that 1,000 deaths in 2004 being attributable to outdoor air pollution in Sri Lanka[15].

Economic cost of air pollution
The estimated economic cost of adverse health effects of air pollution is immense. The expenses can be due to personal or institutional health costs (medical costs, nursing care, drugs, etc.), productivity loss due to absence from work or inefficiency, etc. [20]. Studies have estimated the probable cost due to air pollution and economic benefit by mitigation. A case study in Kanpur, India (population 2.7 million) estimated if the air quality levels are improved to safe levels (i.e., ambient air quality standards of Kanpur), the annual economic benefit is approximately 3.96 million US dollars (USD). Hong Kong has relatively clean air compared to other Asian cities. However, suspended particles and nitrogen dioxide levels exceed the Hong Kong air quality standards. Further reduction of these pollutants below the recommended standards will accrue benefits ranging between USD 1.6 billion and USD 5.5 billion[21]. The annual costs of selected health outcomes due to IAP is estimated to be USD1.4 billion (0.4% of Gross National Income (GNI)) in Indonesia, USD 86 -435 million (0.1- 0.4% of GNI) in the Philippines and USD 12.5 million (1.4% of GNI) in Timor-Leste. The average solid fuel use in Indonesia, Philippines and Timor-Leste are 45%, 49% and 98% respectively[22].

Many countries which have developed an effective Air Quality Monitoring approach have discovered that the benefits received from emission reductions are usually much higher than the cost of implementing emission reduction measures. For example, a study in USA found that the impact of three important regulations on outdoor air quality management that cost from USD 23–26 billion in implementation between 1992–2002, resulted in estimated benefits of USD 120–193 billion[23].

The findings of a study based on outdoor air quality levels of Colombo suggest that 20% of the asthma cases recorded at Lady Ridgway Hospital and 2% of cases reported to the National Hospital, Colombo could be attributed to PM_{10} pollution level in Colombo [24]. The possible economic loss due to outdoor air pollution due to $PM_{2.5}$ in Colombo has been estimated to be about USD 7.0 million[25].

Sources and constituents of air pollution
Air pollutants can be primary or secondary. Primary pollutants are emitted into the atmosphere from a source such as a factory chimney or exhaust pipe, or through suspension of contaminated dusts by wind.

Secondary air pollutants are formed within the atmosphere itself. They arise from chemical reactions of primary pollutants, possibly involving the natural components of the atmosphere, especially oxygen and water. Air pollutants can also be classified by the physical state of a pollutant as gaseous or particulate (i.e., particulate matter (PM)). Gaseous air pollutants are those present as gases or vapours such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2) etc. Particulate air pollutants comprise material in solid or liquid phase suspended in the atmosphere. Such particles may be either primary or secondary and of varying sizes. PM less than 2.5 micrometers in diameter ($PM_{2.5}$) is one of the most hazardous pollutants that can penetrate up to the lung alveoli.

a. Indoor air pollution

The sources, pollutant types, density of IAP and human exposures are a result of complex interactions between the structure, building systems, indoor source strength, removal and deposition rates, indoor mixing and chemical reactions, furnishings, the outdoor environment and source strength, and the practices and behaviours of the inhabitants [26,27]. Thus, the variations could be seen at different levels (i.e., developed vs. developing countries; between developing countries; between cities/regions of a country; between households/buildings).

IAP in developing countries, as compared to developed countries, is disproportionately higher due to difference in sources of air pollution. In the developing world, the majority of the population use solid fuel for cooking and heating purposes. For example, 76% of all global PM air pollution occurs indoors in the developing world [28]. $PM_{2.5}$ densities may increase to the range of milligrams per cubic meter inside kitchens during cooking, far in excess of the 24-hour average limit of 25 $\mu g/m^3$ recommended by the WHO [29]. It is estimated that about 3 billion of the world's population and up to 90% of rural households in developing countries use solid fuel as the main energy source for cooking and/or heating [14,30]. Solid fuel can be biomass or coal. Biomass fuel includes wood (unprocessed and charcoal), dung or crop residues. The type of solid fuels used differs by country. For example, coal is commonly used in China [31]. In Sri Lanka, solid fuels are limited to wood while coal, charcoal, cow dung are generally not used [32]. Wood was the principal cooking fuel used by 78.3% and 78.5% of households in 2000 and 2007, respectively. In 2007, 96.3% of estate sector households used wood as compared to 84.2% in the rural sector and 34.6% in the urban sector [33,34].

Indoor tobacco smoking is another important source of IAP which exposes non-smokers to tobacco smoke (i.e., SHS). SHS comprises a mixture of main-stream smoke (smoke first inhaled by an active smoker and then exhaled) and side-stream smoke (smoke emitted between puffs). Side-stream smoke accounts for about 85% of total SHS, the rest comprising mainstream smoke [35]. SHS is a complex mixture of more than 4000 chemicals, of which, more than 40 are identified carcinogens in vapor and particle phases [36]. SHS can be more carcinogenic than mainstream smoke inhaled by active smokers [35].

With rapid urbanization and industrialization, ambient air pollutant concentrations in many cities in developing countries far exceed current WHO air quality guidelines [37]. Pollutants with high outdoor concentrations infiltrate indoors. Infiltration and trapping of pollutants vary depending on local topography and the configuration of buildings [38].

A spectrum of biological pollutants is released from dust mites, molds, fungi, bacteria, pests (cockroaches, mice, rats) and also from by-products of humans and pets. These pollutants may release microbial products such as endotoxins, microbial fragments, peptidoglycans and various types of allergens [39]. Several common products used in households may also release pollutants. Such products include personal care products, household products such as finishes, rug and oven cleaners, paints and lacquers, paint strippers, pesticides, mosquito repellants, dry-cleaning fluids, building materials, and home furnishings etc. Uranium-bearing soil releases radon which may aggregate in poorly ventilated or closed indoor air environments [40,41].

b. Outdoor air pollution:

Widely known and commonly found air pollutants in ambient air (also known as "criteria pollutants") are PM, ground-level ozone (O_3), carbon monoxide (CO), sulfur oxides (SOx), nitrogen oxides (NOx), and lead (Pb)[42]. There are a range of mobile (e.g., road vehicles, railway trains, ships) and stationary (e.g., industries, indoor household sources) sources of outdoor air pollution [29]. Globally, 32% of the population live in areas exceeding the WHO Level 1 Interim Target of 35 $\mu g/m^3$, largely contributed to by South and East Asia [43]. Many Asian cities are among the most polluted in the world[37].

Air pollution does not stop at national borders; thus countries in the region are both sources and receptors, referred to as trans-boundary air pollution. The influence of dust storms in Qatar, Iran, and high smoke episodes in Northern India could be observed in chemically analyzed air quality samples collected at the Atomic Energy Authority and the Colombo

Fort air quality monitoring stations in Sri Lanka[44]. Limited air quality monitoring done in Anuradapura in from year 2002 to 2004 showed evidence of trans-boundary air pollution[45].

Air pollution levels in Sri Lanka

a. Indoor air pollution

Table 1 provides household indoor air quality levels reported in Sri Lankan studies. A recent study conducted in the Colombo Municipal Council (CMC) area and the Panadura Medical Officer of Health (MOH) area monitored indoor $PM_{2.5}$, NO_2 and SO_2 in main living rooms of 198 households. The study setting in Panadura MOH was at least 1 km away from main arterial roads. The study found that $PM_{2.5}$ levels exceeded recommended guidelines of the WHO in all households in the CMC area and in 70% of households using biomass (n = 42) in the Panadura MOH area. The median $PM_{2.5}$, NO_2 and SO_2 concentrations in households using clean fuels in the CMC area were 47.3, 34.7 and 27.1 $\mu g/m^3$, respectively; in the Panadura MOH area, these concentrations were 19.5, 9.2 and 10.3$\mu g/m^3$, respectively. In both settings, households that used biomass for cooking had the highest median $PM_{2.5}$ levels (urban= 122.3 $\mu g/m^3$; semi-urban=39.1$\mu g/m^3$). In the same study, living in an urban setting, cooking with biomass or kerosene and indoor cigarette smoking were predictors of high indoor $PM_{2.5}$ concentrations[46].

Table 1: Studies monitored indoor air pollution levels in Sri Lankan households

Location Year Author	Number of households Place of measurements	Pollutant	Results
Colombo and Panadura 2011 Nandasena, et al.[46]	65 urban permanent 67 urban semi-permanent 66 semi urban Main living room	$PM_{2.5}$, NO_2 SO_2	clean fuels in urban setting $PM_{2.5}$ = 47.3$\mu g/m^3$ NO_2 = 34.7$\mu g/m^3$ SO_2 = 27.1 $\mu g/m^3$ clean fuels in semi-urban setting $PM_{2.5}$ = 47.3$\mu g/m^3$ NO_2 = 34.7$\mu g/m^3$ SO_2 = 27.1 $\mu g/m^3$ median $PM_{2.5}$ levels in biomass using: urban= 122.3 $\mu g/m^3$; semi-urban=39.1$\mu g/m^3$
Colombo 2010 Ranasinghe, et al.[94]	6 households Main living room	$PM_{2.5}$ TC OC EC	Average 143.7 $\mu g/m^3$ (range 122.8-190.6$\mu g/m^3$) TC = 28.41 ± 4.45$\mu g/m^3$ OC= 321.89 ± 3.79 $\mu g/m^3$ EC = 6.51 ± 1.77 $\mu g/m^3$
Kandy 2008 Amarasekara, et al.[95]	20 households Measurements were done in 4 kitchen types (5 in each type) Improved stove with chimney (K1) Improved stove without chimney (K2) Un-improved stove with chimney (K3) Un-improved stove without chimney (K4)	CO $PM_{2.5}$	K1: CO=0.228ppm,$PM_{2.5}$=0.077mg/m^3 K2: CO = 2.908ppm $PM_{2.5}$= 1.874 mg/m^3 K3: CO = 1.132ppm $PM_{2.5}$= 1.838 mg/m^3 K4: CO = 8.066ppm $PM_{2.5}$= 5.406 mg/m^3
Colombo 2004 Sen anayake [96]	30 households	NO_2 SO_2	Indoor to outdoor ratio ranged from1.11;1.00 to 2.04:1.00 (Measured by passive sampler badges)
Kotte 2000 Lankathilaka, et al.[97]	Number of households not provided. Kitchens	TSP	84% of households using firewood and 54% of households using firewood exceeded the WHO recommendations

TC = Total carbon; OC = Organic carbon; EC = Elemental carbon

If smoking is permitted in indoor public places such as restaurants and pubs, occupational groups and visitors are invariably exposed to SHS against their will. Indoor $PM_{2.5}$ levels were measured in 168 public venues in seven Asian countries including Sri Lanka. The venues included cafes, bars, restaurants and pool parlors (n= 20). The study used the same methodology and monitoring instruments in all settings in all countries. It was found that people were exposed to high $PM_{2.5}$ concentrations than recommended by the WHO. The average indoor $PM_{2.5}$ level was 137g/m^3 ranging from 46g/m^3 in Malaysia to 207g/m^3 in India. These results are consistent with $PM_{2.5}$ levels in public places prior to the smoking ban in indoor places in developed countries[47]. The average $PM_{2.5}$ level monitored in 20 public places in Sri Lanka was 124.9 µg/m^3(range 33 to 299µg/m^3). The $PM_{2.5}$levels in the immediate outdoor vicinity of public places ranged from 18 to 83 µg/m^3. The average $PM_{2.5}$ level found in this study was 3 to 11fold higher than the post legislation levels reported in the same type of public venues in other countries. This study was conducted in 2009, while the law banning smoking in indoor public places was enacted in Sri Lanka in 2006[48].

b. Outdoor air pollution

The 3 year average (from year 2002 to 2005) PM_{10} concentrations reported in Colombo Fort (an urban location) was 73.37 µg/m^3 and in a residential area of Colombo was 58.82 µg/m^3 in an inter-country comparison. The same study reported PM_{10} values of 45.76 µg/m^3 in an urban location in Bangladesh, 37.34 µg/m^3 in Trombay, India, 82.83 µg/m^3 in Vashi, India, 67.45 µg/m^3 in Pakistan, 38.67 µg/m^3 and 25.77 µg/m^3 in an urban and suburban location in Thailand, and 50.29 µg/m^3 in Vietnam[34]. The average annual ambient PM_{10} levels in Colombo over the years have remained relatively stable ranging from 72 to 82 µg/m^3. The WHO recommended annual average concentration of PM_{10} is 20 µg/m^3. This recommendation is based on epidemiological evidence of adverse health effects [8]. In another study, the outdoor $PM_{2.5}$, NO_2 and SO_2 were monitored in three locations in the CMC area for one year (from March 2008 to February 2009). The reported 24 hour average $PM_{2.5}$ and PM_{10} levels were 39.1 µg/m^3 and 60.1µg/m^3, respectively; the annual average levels of NO_2 andSO_2 were 1.7µg/m^3 and 32.7µg/m^3, respectively. Monitoring conducted using the same methodology in the Panadura MOH area (at least 1 km away from main arterial roads) reported that the outdoor 24-hour average $PM_{2.5}$ and PM_{10} levels were 16.6µg/m^3 and 30.9µg/m^3, respectively; the annual average NO_2 andSO_2 levels were 8.9µg/m^3 9.0µg/m^3, respectively. WHO recommends that NO_2 (annual average) should not exceed 40 µg/m^3[49]. In another study, NO_2 and SO_2 exposure levels of city dwellers engaged in different occupations were measured using passive samplers [50]. Bus drivers were exposed to more NO_2 (57.36 µg/m^3) and SO_2 (82.70µg/m^3) as compared to trishaw drivers (NO_2 - 50.18 µg/m^3; SO_2 - 78.36 µg/m^3), shop keepers (NO_2 - 54.91 µg/m^3;SO_2 - 63.29 µg/m^3) and outdoor vendors (NO_2- 37.66 µg/m^3; SO_2 - 35.25 µg/m^3).

Epidemiological evidence

A large number of epidemiological studies from other developing countries provide evidence for the association between air pollution and adverse health effects. A recent review identified sixteen studies done in Sri Lanka that investigated the association between exposure to ambient (n = 10) and indoor (n = 6) air pollution and various health outcomes. A summary of these studies (adapted from Nandasena et al, 2010) is given in tables 2 and 3[51].

Table 2: Studies assessing the health effects of ambient air pollution in Sri Lanka

Reference, study location and data collection period	Study design, subject characteristics and sample size	Exposure air pollutants	Health outcomes	Results	Adjustment for confounding factors	Limitations
Cross sectional studies						
Premaratna R et al.[98] Gampaha district, 1997	Children, 1-12 years (n = 154); adults (n= 304)	Not measured	Respiratory symptoms & peak flow rate	Higher rate of respiratory symptoms and reduction in expiratory flow rate reported in the industrialized area.	No	No measurement of exposure
Senanayake MP et al[87], Colombo, 1998 and 2003	Children, 1-15 years (1998, n= 50; 2003, n = 39)	Blood lead levels	Blood lead levels	6% of children had blood lead levels >10 µg/dl when leaded petrol was used (1998); none had levels > 10 µg/dl, one year after unleaded petrol was introduced.	No	Small sample size. Comparison of different birth cohorts.
Amarasinghe J.N.P.et al[88], Colombo. 2002	Policemen, trafic (n = 64); non-trafic (n= 64)	Blood lead levels	Potential symptoms and signs resulting from high blood lead levels	Abdominal discomfort, tremor and hypertension higher in traffic policemen as compared to non- traffic policemen	No	Control group may also have had a high exposure during the busy hours leading to misclassification

Table 2: Studies assessing the health effects of ambient air pollution in Sri Lanka

Reference, study location and data collection period	Study design, subject characteristics and sample size	Exposure air pollutants	Health outcomes	Results	Adjustment for confounding factors	Limitations
Mistry R. et al[72], Galle and Chandigarh. 2004	Children, 13-14 years (Galle, n = 1162; Chandigarh,n=575)	No specific types are measured	Wheezing	Occurrences of wheezing was higher in Galle as compared to Chandigarh	No	No measurement of exposure
Nandasena YLS et al[71], Colombo and Ampara districts, 2005	Children, 9 – 15 years (n=482)	SO_2 NO_2 PM_{10}	Respiratory symptoms	Respiratory symptoms were higher in Colombo as compared to the rural area. Associations were overridden by household risk factors.	Adjusted for cooking fuel type and mosquito coil use	Only respiratory symptoms are considered
Perera GBS et al[99], Colombo and Ampara districts 2005	Adults (n= 587)	SO_2 NO_2 PM_{10}	Respiratory symptoms	Occurrence of respiratory symptoms were higher in Colombo as compared to the rural area	Adjusted for cooking fuel type and mosquito coil use	Only respiratory symptoms are considered.

Table 2: Studies assessing the health effects of ambient air pollution in Sri Lanka

Reference, study location and data collection period	Study design, subject characteristics and sample size	Exposure air pollutants	Health outcomes	Results	Adjustment for confounding factors	Limitations
Elangasinghe MA et al[100], Kandy, 2006	12-16 year school children (n= 760)	PM_{10}	Respiratory health	32% of children of village school had a health indicator of 1 (a measure of perfect respiratory health) while only 8% from the city school had an index of 1.	No	Health indicator constructed by authors but not validated.
Other Study Designs						
Senanayake, M.P., et al.[73], Lady Ridgeway Children's Hospital, Colombo, 1998-1999	Ecological study, children under 12 years (n =41032)	NO_2, SO_2	Emergency reporting for nebulization	Episodes of nebulization positively correlated with most polluted days ($p < 0.05$)	No	No measurement of exposure of the children; pollutant data from single monitor in the city
Sirithunga TLJC et al[70, 101], Kandy district, 2004.	Follow-up study children 7-12 years (n = 1033)	SO_2 NO_2 Ozone	Respiratory symptoms	Occurrences of respiratory symptoms were higher in the Kandy city area as compared to the rural area.	Yes	Only outdoor passive samplers used; indoor air quality predicted with proxy variables

Table 2: Studies assessing the health effects of ambient air pollution in Sri Lanka

Reference, study location and data collection period	Study design, subject characteristics and sample size	Exposure air pollutants	Health outcomes	Results	Adjustment for confounding factors	Limitations
Dharshana KGT and Coowanitwong N[24] LRH hospital, Colombo	Ecological study	PM_{10}	Respiratory diseases	Diseases categories included bronchitis, emphysema and other chronic obstructive pulmonary diseases; positive correlation ($r=0.717$; $p=0.01$).	No	Colombo Fort monitoring station may not be representative of the whole study area.

Note: Adapted from Nandasena et al, 2010[15]

Table 3: Studies assessing the health effects of indoor air pollution in Sri Lanka

Reference, Study Location and data collection period	Study Design Subject Characteristics and sample size	Exposure air pollutants	Health outcomes	Results	Adjustment for confounding factors	Limitations
Cross sectional studies						
Karunasekara K.A.W. et al[102] Gampaha district 1998	Children, 5-11 years, asthmatics (n= 441); non asthmatics (n= 1510)	No specific types are measured	Asthma	Prevalence of asthma was significantly higher in the presence of firewood smoke	Yes	No measurement of exposure
Lankatilake et al 1999[97]Kotte Medical Officer of Health area	Households = 397 children = 604 women = 130	Respirable dust	Respiratory symptoms	Respiratory symptoms were significantly higher in houses using firewood	Yes	Only respirable dust levels were measured
Pathirana S. M. et al[85] Kegalle and Kalutara districts. 2004	New borns (n=369)	No specific types	Low birth weight	Low birth weight was associated with fuel type and kitchen characteristics	No	No measurement of exposure

Table 3: Studies assessing the health effects of indoor air pollution in Sri Lanka

Reference, Study Location and data collection period	Study Design Subject Characteristics and sample size	Exposure air pollutants	Health outcomes	Results	Adjustment for confounding factors	Limitations
Case-control Studies						
Karunasekara K.A.W. et al[103] Colombo North Teaching Hospital 1996-1997	Children 1-10 years, age matched cases and controls (n=300)	No specific type	Asthma	Dust at home was a significant risk factor for asthma	Yes	No measurement of exposure
Perera M.A.K.K. P. et al[104] National Cancer Hospital 2004	Lung cancer patients (n= 128) and controls (n= 128)	No specific type	Lung cancer	No significant association with biomass exposure	No	No measurement of exposure
Ranasinghe M.H. et al[84] National Eye Hospital, Colombo 2004	Patients with cataracts (n= 197) and controls (n= 190)	No specific type	Cataract	Cataracts significantly associated with biomass exposure	No	No measurement of exposure

Note: Adapted from Nandasena et al, 2010[51]

Respiratory health

Many respiratory conditions are known to be associated with air pollution. Acute respiratory tract infections have a definitive association with air pollution. Risk factors of acute lower respiratory tract infections in children include malnutrition, low birth weight (≤ 2500 g), non-exclusive breastfeeding (during the first 4 months of life), lack of measles immunization within the first 12 months of life, IAP and crowding[52].

1. Indoor air pollution and respiratory health

Based on 24 studies, an overall pooled odds ratio of 1.78 (95% CI, 1.45–2.18) was reported for pneumonia among under-five children exposed to IAP due to solid fuel use[13]. Parental smoking has a significant effect on respiratory health of children as parents may smoke at home and SHS exposure is unavoidable in many circumstances [53]. SHS exposure has been shown to be strongly associated with the occurrence of middle ear infections in children. A recent meta-analysis based on 61 epidemiological studies reported that living with a smoker was associated with an increased risk of middle ear infections in children; the risk was 1.62 (95% CI, 1.33-1.97) times higher for maternal postnatal smoking and 1.37 (95% CI, 1.25-1.50) times higher for smoking by any household member [54].

Evidence for the association between exposure to solid fuel and asthma is contradictory[5]. The pooled OR of four studies on asthma among children exposed to biomass fuels was 0.50 (95% CI 0.12 to 1.98) [55]. However, wheezing, a major clinical expression of asthma, [56] had shown a clear association with solid fuel smoke exposure among children. Wheezing can be a clinical symptom of lower respiratory tract infections, pneumonia, etc. [56]. A recent meta-analysis estimated that the onset of asthma is 1.33 times (95% CI = 1.14 - 1.56) and ever asthma is 1.48 times (95% CI, 1.32 - 1.65) higher among children exposed to SHS [57]. Exposure to mold increases the susceptibility to asthma [58]. A pooled OR of 1.35 (95% CI, 1.20 - 1.51) was reported for mold exposure and asthma [59]. The residential concentrations of some classes of volatile organic compounds have been associated with asthma. However, microbiologic agents in dust have shown limited suggestive associations with asthma, including both positive and negative associations for some agents[60].

Exposure to SHS and solid fuels indoors are related to the development and exacerbation of chronic obstructive pulmonary disease (COPD)[61]. A recent meta-analysis has found that solid fuel exposure is associated with COPD in rural women (odds ratio 2.40, 95% CI: 1.47–3.93)[55].

Exposure to SHS and solid fuels is also shown to be associated with hypopharyngeal, laryngeal and lung cancers [62]. However, the associations are stronger for exposure to coal while it is only suggestive for exposure to biomass cooking.

A large number of studies from developing countries suggest that chemicals released from other sources are associated with respiratory health[63].

Lung functions are one of the strongest predictors of mortality in adults. Factors that affect lung functions in adults are strongly dependent on the growth and development of lung functions in childhood. IAP affects lung functions and lung growth in children [64,65].

Recent epidemiological studies in developing country settings have provided evidence that use of unclean cooking fuels (i.e., solid fuel, kerosene) and exposure to SHS are associated with tuberculosis [66]. A recent case control study on tuberculosis in Nepal reported an adjusted OR (aOR) of 1.21 (95% CI, 0.48–3.05) for using a biomass-fuel stove , an aOR of 3.36 (95% CI, 1.01 - 11.22) for using a kerosene-fuel stove, an aOR of 3.45 (95% CI, 1.44 - 8.27) for using biomass fuel for heating, and an aOR of 9.43 (95% CI, 1.45 - 61.32) for using kerosene lamps for lighting[67].

2. Outdoor air pollution and respiratory health

Similar to IAP, a large number of studies have provided evidence for the relationship between outdoor air pollution, especially for exposure to traffic-related air pollution, and respiratory health including respiratory symptoms, upper and lower respiratory tract infections, pneumonia, bronchitis, asthma, poor lung functions, reduced lung growth and lung cancer[37]. Estimates show that an increase of PM_{10} by $10\mu g/m^3$, increases the daily mortality from acute respiratory tract infections among children under 5 by1.66% (95%CI, 0.34 – 3.0) in Western countries.

3. Air pollution and respiratory health studies in Sri Lanka

Tables 2 and 3 provide a complete list of studies on air pollution and respiratory health conducted in Sri Lanka up to 2009. A panel study of children aged 7 – 10 years was conducted in two settings, namely, in the CMC area and in the Panadura MOH area (at least 1 km away from main arterial roads). Three panels of children (aged 7-10 years, n = 204 children in each panel) were followed-up for one year (panel 1 = children resident in semi-permanent households in setting one; panel 2 = children resident in permanent households in setting one; panel 3 = children resident in permanent or semi-permanent households in setting two). Following the baseline respiratory health assessment, a daily symptom diary was maintained for each child throughout the one year of follow-up. Reported air quality levels have been described in the section on "air quality levels in Sri Lanka". Living in setting one, exposure to SHS, having pets in home ($\geqslant$50% of the time) and parents being wheezers were significant risk factors of wheezing in children during follow-up. The rates of shortness of breath episodes were 0.211, 0.200 and 0.146 episodes per 100 person days of children of panels 1, 2 and 3, respectively. The rates of wheezing days were 0.841, 0.701 and 0.417 days per 100 person days of children of panels 1, 2 and 3, respectively. Lung functions were not significantly different in children of the two settings[68,69].

Sirithunga et al.[70] measured outdoor air pollutant levels in home environments of school children in an urban and a rural area in the Kandy district and assessed respiratory symptoms over a one-year period on a daily basis using health diaries. Outdoor NO_2, SO_2 and Ozone were monitored with passive samplers and exposure to indoor pollution was measured using proxy parameters. Occurrence of respiratory symptoms was collected by diaries on a daily basis. The occurrence of cough, nasal discharge and throat irritation were 1.12 (95%CI = 1.05-1.19), 1.17 (95%CI = 1.09-1.24) and 1.48 (95%CI = 1.31-1.67) times higher among children in the Kandy urban area, respectively, as compared to those of the rural area. Lung functions were not significantly different between the urban and rural subjects.

School children are exposed to high levels of pollutants due to overcrowding of major schools in urban areas, especially in Colombo. The prevalence of respiratory symptoms among school children attending a school in Colombo situated close to a busy main road was significantly higher than that of children attending a school situated in a peripheral area (cough - OR = 1.33, 95% CI = 1.12-2.48; presence of phlegm - OR: 1.66, 95%CI = 1.12-2.46; wheezing - OR: 1.29, 95% CI = 0.80- 2.10). Pollutant (NO_2, SO_2, and TSP) levels were significantly higher in the premises of the urban school (in the CMC area) as compared to the school located in the Padiyathalawa MOH area[71].

Mistry et al.[72] compared the prevalence of asthma among 13 to 14 year-old children in Galle (n = 1162) (described by the authors as an unplanned, busy city with predominant use of kerosene or firewood for cooking in Sri Lanka) and in Chandigarh (n = 575) (a city defined by the authors as a planned, clean and using smoke-free household fuel in India). Children in Galle were at an increased risk of life-time wheezing (Galle-28.7%, Chandigarh-12.5%; the prevalence odds ratio (POR) = 2.3, 95% CI = 1.8-2.9) and for wheezing in the previous year (Galle-21.9%, Chandigarh-10.4%, POR = 2.1, 95% CI =1.6-2.7) as compared to children from Chandigarh.

An ecologic study examined the air pollutant levels measured at the Colombo Fort monitoring station and rates of hospital attendance for wheezing needing emergency treatment at the Lady Ridgeway Hospital for Children in Colombo. About 30,932 children required nebulizer therapy in the emergency treatment unit (median daily attendance 85) during the 12-month period beginning in July 1998. The highest number of episodes of nebulization occurred on the most polluted day (with respect to SO_2 and NO_2) and the lowest number of nebulizations occurred on the least polluted day in a given week, in a significant number of weeks throughout the year (binomial test, p = 0.05)[73].

b. Non-respiratory health

1. Indoor air pollution and non-respiratory health

Based on a recent meta-analysis, IAP from solid fuel increased the risk of percentage of low birth weight children (OR = 1.38, 95% CI, 1.25 - 1.52) and stillbirths (OR = 1.51, 95% CI, 1.23 - 1.85) and reduced the mean birth weight (- 95.6g, 95% CI, 68.5 - 124.7)[74]. Studies also provide evidence of the association of IAP and neurological outcomes such as neural tube defects [75], neurodevelopmental performance among school aged children [76], cardiovascular diseases[77], diabetes[78], cataracts[79]; etc.

2. *Outdoor air pollution and non-respiratory health*

Increase of the short-term exposure to PM_{10} by $10 \mu g/m^3$ is estimated to increase the daily mortality from all natural causes by 0.6% (95% CI, 0.3 - 0.9). These associations were reported between mean PM_{10} concentrations of 51.6 -141.8 $\mu g/m^3$[37].

New evidence is emerging for the relationship between traffic related air pollution and diabetes mellitus [80] and neurological effects including motor, cognitive and behavioral changes[81]. There are a large number of epidemiological studies, mostly from developed countries, that provide convincing evidence for the strong association between outdoor air pollution and cardiovascular mortality. These studies provide information on increase of atherosclerosis with long term exposure and subsequent myocardial infarction, acute triggering of myocardial infarction and arrhythmias etc. [82,83]. It has been shown that pre-existing cardiovascular disease and smoking predispose individuals to adverse events with exposure to air pollution[82].

3. Air pollution and non-respiratory health studies in Sri Lanka

Ranasinghe et al. [84] found an association ($p < 0.05$) between biomass exposure and cataract by comparing cataract patients (cases, n = 197) with patients admitted for other eye problems (controls, n = 190) at the National Eye Hospital, Colombo. A cross-sectional study reported that the availability of a separate kitchen (OR = 2.7, 95% CI = 1.6-4.7), use of less clean cooking fuel (OR = 3.9, 95% CI =1.8 - 8.5) and not having adequate ventilation in the cooking area (OR = 2.7, 95% CI =1.3 - 5.3) were significant predictors of low birth weight in the Kegalle and Kalutara districts[85].

Following the introduction of unleaded gasoline, atmospheric lead levels reduced by 81.5%, 82% and 84% in three locations in Colombo [86]. Senanayake et al.[87] measured blood lead levels of a sample of children living near a traffic congested junction in Colombo in 1998 and then one year after the introduction of unleaded gasoline. In 1998, 6% of children had blood lead levels above 10 µg/dL; in 2003, not a single child had a blood lead level >10µg/dl (range 1.67 µg/dl to 9.7 µg/dl). Amarasinghe et al. [88] measured blood lead levels of traffic policemen (n = 64) and non-traffic policemen (n =64) based in Colombo in 2002. The mean blood lead levels in traffic and non-traffic policemen were 7.47 µg/dl (SD = 2.89) and 7.06 µg/dl (SD = 2.93), respectively.

Future directions of prevention

Compared to many other developing countries with a similar profile of solid fuel use, and indoor and outdoor air pollution, Sri Lanka is unique in having good public health indicators and a good health status among its population. Sri Lanka has a better immunization coverage, better nutrition indicators, malaria at elimination phase, low prevalence of HIV/AIDS, better health seeking behavior of community, widely accessible primary health care and a well-established public health system as compared to other neighbouring South Asian countries. This may have contributed to in some way to mitigating the adverse effects of air pollution. However, the attributable fraction of a given health outcome due to air pollution could be high as other risk factors have been modified accordingly. Thus, the further improvement of health indicators requires addressing unattended issues such as exposure to air pollution. The broad range of likely health impacts of air pollution in Sri Lanka means that a variety of methods and strategies should be applied for mitigating the adverse health effects and minimizing exposures.

1. Indoor air pollution

People generally move up from using unclean to using clean fuels as socio-economic conditions improve [5].There may be other factors involved in shifting towards clean cooking fuels such as their relative availability, cultural practices and attitudes [32]. As a consequence, shifting from unclean to clean cooking fuels may be slow and will continue for many more decades [31]. Thus, tailor made cook stove interventions to reduce IAP is of prime importance.

A successfully implemented cook stove intervention may contribute significantly to the reduction of exposure [89]. Not only the improved cook stove, the availability of a functional chimney and adequate ventilation is essential to minimize the IAP to an acceptable level. About 27% of Sri Lankan households use biomass fuel for cooking inside the main building which does not have a chimney[32]. The reduction of exposure to acceptable levels is challenging and needs a well-integrated and coordinated approach with commitment on design and distribution to needy communities with wide community acceptance, high energy efficiency and marked reduction of emissions. Further, the change of behaviors and practices of communities is essential for the sustainability of improved cook stove interventions. Essentially, the "threat" of IAP from a health point of view should be emphasized among traditional stove users through appropriate media and language targeting even the most rural communities. Improving awareness of adverse health effects of IAP among health administrators, physicians and primary health care workers is essential as they are in a better position to contribute to preventive activities.

Table 4: Cook stove interventions in Sri Lanka

Cook stove type	Introduced Year	Remarks
Muti-pot hearth	Early 1950s	Developed and used by the migrated South Indian community worked in the tea plantation
Herl Chula'	1953	Adapted from South India
IDB concrete stove	1972	Not successful
IDB brick stove	1975	Not successful
CISIR/TIMCO Charcoal Stove	1978	Successful. Commercialized by Timber Cooperation. Programme stopped due to shortage of charcoal supply. Urban focus
Sarvodaya Wood Stove	1979	This programme had broader objectives and had a tremendous impact on the improved cookstove developments in Sri Lanka. Rural focus
Two piece two pot (pottery liner stove with a mud insulation)	1982	Developed by Sarvodaya/ITGA and promoted by Ministry of Power and Energy in 1984, more than 400,000 stoves were installed.
Anagi 1 and Anagi 2 stoves	1987	Initially promoted by CEB since 1991. Integrated Development Association (IDEA) has been involved with training of potters, commercialization and distribution of Anagi– 2 up to date. Angi 1 failed. Anagi 2 is the most successful cook stove program in Sri Lanka. Urban and rural focus
IDB Stove	1989	Not successful as Anagi stove
NERD Center Stove	1989	Not successful as Anagi stove
NERD Wood Gasifier Stove	2006	Efficiency proven but did not accepted by community. Urban focus

CEB: Ceylon Electricity Board

CISIR: Ceylon Institute of Science and Industrial Research

IDB: Industrial Development Board

ITGA: Intermediate Technology Development Group

NERD: National Engineering Research and Development Centre

Several cook stove interventions have been implemented in Sri Lanka since the 1950s (Table 4) but most of them have been unsuccessful. One cook stove programme, the "Anagi stove", was well accepted by, and had penetrated into, communities of Sri Lanka, perhaps one of the most successful programmes in developing countries. The main reasons for the high success rate could be the cultural acceptance and commercialization strategy. However, the "Anagi stove" has not been adequately evaluated scientifically for its efficacy. Limited exposure measurements indicated that the use of "Anagi stove" itself does not reduce the exposure to acceptable levels [89]. Thus, the possibilities of further modification of the "Anagi" stove or introduction of a novel cook stove intervention combined with modifications of kitchens may be considered. Many of the cook stove programmes implemented in other developing countries have been unsuccessful due to a lack of cultural acceptance[90].

Sri Lanka was the first in the South-East Asia Region to ratify the WHO Framework Convention on Tobacco Control. Legislature has been enacted in Sri Lanka to ban smoking in public places since 2006, prior to many of the regional countries (e.g., India in 2008, Nepal in 2011). Legislature banning smoking in public places reduces exposure to SHS [47,91]. However, it is important to enforce the law universally [48]. Further, these laws are not practically useful at household level where most exposure occurs among vulnerable groups such as children and pregnant women [53]. Thus, extensive awareness campaigns targeting change of indoor smoking habits in households is important, despite the fact that such change of habits is difficult to achieve.

Studies have shown that as a country's income level increases, cigarettes are engineered to reduce emission levels [92]. Thus, the cigarette design and emission levels should be evaluated and stringent standards for emissions set. In addition, vigorous implementation of the smoking prevention strategies recommended by WHO will definitely reduce exposure to SHS[93].

Among the steps taken in the recent past, the Vehicle Emission Testing (VET) programme needs to be highlighted. The monitoring and evaluation of strategies is greatly limited due to the lack of an effective air quality monitoring network.

Thus, the impact of such strategies, some of which utilize a considerable amount of public money is mostly unknown. For example, modification of existing interventions such as the VET programme needs actual air quality levels in a representative sample of urban cities in Sri Lanka. Further, there are major limitations in tracking human exposure and assessing the actual public health impact. The availability of stringent standards by itself is of little or no use if the air quality that citizens are exposed to is unknown. Therefore, establishing a modern ambient air quality monitoring network, at least covering the main busy cities in the country, is an early need. Many regional countries operate an extensive network for air quality monitoring. In Kathmandu, Nepal, there are 7 monitors as compared to the whole of Sri Lanka having a single functioning automated monitor. Some Asian countries such as Malaysia and South Korea have web based real time online air quality monitoring systems that provide air quality indices. "Air quality index" converts the actual air quality levels to an index which the general public can understand. Although a move was initiated to provide an air quality index in Sri Lanka, this is not functioning due to a variety of reasons.

Table 5: Major steps implemented to mitigate outdoor air pollution

Year	Activity
1992	Clean Air 2000 Action Plan
1994	Regulations of National Ambient Air Quality Standards
1996	Establishment of Ambient Air Quality Monitoring Stations in Colombo City
2000	National Policy on Urban Air Quality Management
2001	Establishment of AirMac under the Ministry of Environment & Natural Resources
2002	Introduced Unleaded Petrol Island wide
2003	Regulations of Vehicle Emission and Fuel Standards, and Emission Standards for Importation of Vehicles
2004	Establishment of Clean Air Sri Lanka (CleanAirSL)
2004	Introduced Low Sulfur Diesel Euro I
2005	Clean Air Action Plan 2015
2008	Banning of importation of two-stroke engine three- wheelers
2008	Encourage importation of Eco friendly Vehicles through new tax structure
2008	Implementation of Vehicle Emission Testing Program
2008	Amended the existing ambient air quality standards incorporating PM_{10},and $PM_{2.5}$
2012	Final phase of Clean Air Act formulation
2012	Final phase of Formulation Stationary Sources Emission Standards

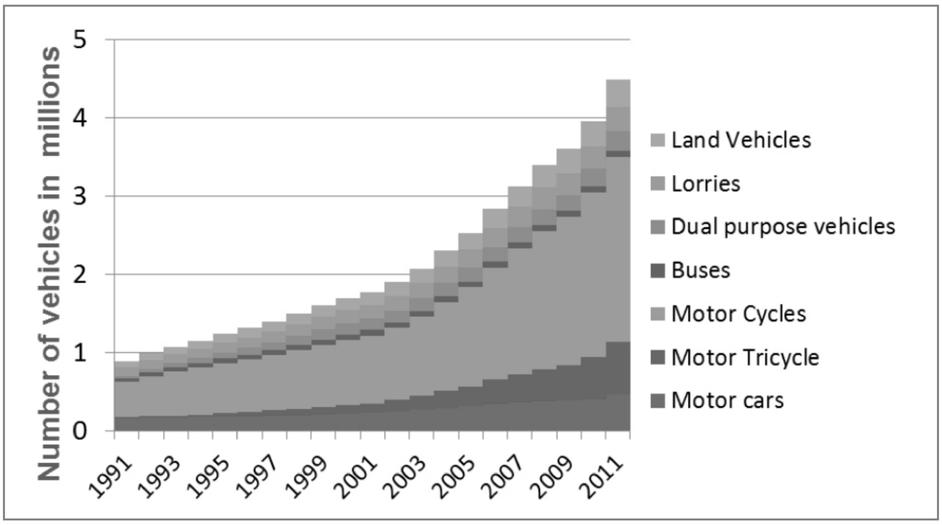
With the "modernization" of households and household practices, a spectrum of hitherto unknown chemical products has been introduced to Sri Lankan households and their adverse effects are yet to be elucidated. Hence, it is important to quantify the epidemiological risk associated with these substances as an initial step in designing mitigating strategies.

2. Outdoor air pollution

The programs implemented to mitigate the outdoor air pollution in Sri Lanka are summarized in Table 5.

The recent "green" city concept and proper traffic management with expansion of the road network including highways, expressways, circular roads and bypasses will contribute to improve of air quality especially in busy cities with reduction of traffic emissions and efficient removal of pollutants. However, the markedly increasing vehicle fleet has negated the actual benefits of these strategies. Figure 1 shows the trend of vehicle registrations in Sri Lanka. More than 500,000 vehicles were registered during 2011; the current active vehicle fleet on Sri Lankan roads is estimated to be over 2.7 million. The estimated active vehicle fleet in 2000 was 1.2 million. On average, 250 000 vehicles enter the Colombo city on a daily basis. In Sri Lanka, around 80% of vehicular PM emissions come from diesel engines. In Sri Lanka, diesel vehicles and vehicles with large engine capacities have benefited with favourable tax structures, especially for a privileged few, as compared to relatively clean fuel consuming low capacity engine vehicles in the recent past. It is noteworthy that taxes on hybrid vehicles that consume much less fuel and pollute less were increased in Sri Lanka in the recent past; such policies are detrimental both economically and health wise in the long term. Traffic related air pollution in Sri Lanka can be controlled only with a strict, long term traffic management policy. The Singaporian traffic management policy includes restriction of vehicle ownership, the conversion of the vehicle fleet to consume less polluting efficient energy sources, upgrading the public transport system to a highly efficient one, close monitoring and enforcement of the law, and charging high parking fees. Further, Singapore realizing that the economic and health costs would be much higher, if its booming industrialization drive is not adapted, was committed to adopting a "green city" strategy; many other counties have adopted the concept of "pollute now and clean up later". There are many other strategies that have been deployed by other countries which may be implemented in Sri Lanka (Table 6). These include control of emissions from diesel vehicle engines by fixing devices that trap pollutants (retro fitting devices) (e.g., Hong Kong), tax incentives for efficient pollution control equipment or devices (e.g., Singapore), conversion of all existing 2 stroke trishaws to compressed natural gas (e.g., Thailand), and strong high quality inner-city transport systems (e.g., Singapore, Seoul, Hong Kong) etc.

Figure 1: Vehicle growth in Sri Lanka from 1991 to 2011



Source: Department of Motor Traffic

Power generation and industries also contribute to outdoor emissions in Sri Lanka. The last of the mega hydro-electric power plants in Sri Lanka (Upper Kotmale) will be commissioned shortly. This implies that the increasing demand in the future, estimated to be about 8-10% per annum in the next few years will have to depend on coal, fossil fuels or renewable sources of energy. It is heartening to note that the Ministry of Power and Energy is keen on developing renewable sources of energy such as solar and wind power. However, high taxes for the necessary equipment and lack of incentives for power generation are the main demotivating factors. Nuclear energy may also be a possibility in the future. However, the benefits and adverse effects of nuclear energy need to be thoroughly studied in the Sri Lankan context before embarking on such a mission.

Stationary emission standards are yet to be legally enforced. Although environmental certification is compulsory for all industries, it is not universally

Table 6: Other outdoor air pollution mitigation options implemented in Asian countries

Other options for mitigation of outdoor air pollution	Regional examples
Adopt cleaner alternatives to diesel in all practical situations	Hong Kong
Control emissions from remaining diesels with devices that trap pollutants (retro fitting devices)	Hong Kong, South Korea
Strong vehicle emission inspections with stringent standards and strict law enforcement against smoky vehicles	Hong Kong
Promote better vehicle maintenance and eco-driving habits.	Hong Kong
Industries are requested to plant trees to mitigate their CO^2 emissions	Singapore
Strategic land use planning: for example, residential, commercial, catchment areas, parks and open places and industries.	Singapore
Tax incentives for efficient pollution control equipment or device	Singapore
Restricting car ownership and encouraging car pools	Singapore, Hong Kong
Regularly updating online air quality levels and air quality index	Malaysia, Singapore, South Korea
Text message containing a specific location information code and receive air quality data by return.	South Korea
Conversion of existing 2 stroke trishaws to compressed natural gas	India, Bangladesh, Thailand, Japan
Strong high quality inner-city transport systems	Hong Kong, Singapore, South Korea
Safe and extensive pedestrian paths	Hong Kong

applied to date. A considerable number of industries emitting unhealthy levels of pollutants are located very close to high residential areas. Strategic land use planning for industries and establishing the pollutant control requirements for all industries is an early requirement.

Conclusions

It can be surmised that air pollution contributes to considerable disease burden in Sri Lanka, based on reported air quality levels in Sri Lanka, limited in-country epidemiological studies and evidence from epidemiological studies conducted in other countries in the region. In brief, Sri Lanka is no different from other countries in a similar stage of development. The policy makers prerogative should be to take bold decisions on air pollution mitigation policy matters. There are many examples within the region to make informed decisions. It is necessary to have a national level action plan to mitigate effects of air pollution. Further, it is essential to generate in-country robust evidence to understand the actual scenarios. Raising awareness of the problem is needed and one essential target category is health professionals; the existing public health system can play a significant role in mitigation activities at community level. Importantly, exposure to air pollution is a modifiable risk factor that has remedial actions. Multidisciplinary and multi-sectoral efforts are needed from policy makers, the government and private sectors, the community and individuals to ensure a healthier Sri Lanka.

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