HEALTH IMPACTS OF DIESEL VEHICLE EMISSIONS: THE CASE OF COLOMBO

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ADB = Asian Development Bank
ARMC = Air Resources Management Center
BLL = Blood lead levels
CAMP = Continuous Air Quality Monitoring Programme
CEA = Central Environment Authority
COI = Costs of illnesses
CPC = Ceylon Petroleum Corporation
CR = Concentration response
D/P = Dual purpose
DVP = Diesel-powered vehicles
DWL = Dead-weight loss
H/D = Heavy-duty vehicles
I/M = Inspection and maintenance
L/D = Light-duty vehicles
MC = Motor cycles
MEIP = Metropolitan Environment Implementation Programme
MSC = Marginal social cost
NBRO = National Building Research Organization
NHSL = National Hospital of Sri Lanka
NO_2 = Nitrogen dioxide
SPC = State Pharmaceuticals Corporation
OPD = Out-patient dispensary
OECD = Organization for Economic Corporation and Development
PAH = Polycyclic aromatic hydrocarbons
ppm = parts per million
PM_{10} = Particulates with an aerodynamic diameter less than 10 microns
$PM_{2.5}$ = Particulates with an aerodynamic diameter less than 2.5 microns
PVP = Petrol-powered vehicles
SC = Social cost
SJGH = Sri Jayawardenapura government hospital
SPM = Suspended particular matter
SO_2 = Sulfur dioxide
USEPA = U.S. Environmental Protection Agency
UC = User charges
VSL = Value of statistical life
WHO = World Health Organization

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ABSTRACT

This study makes an attempt to assess the health effects of diesel vehicle exhaust emissions in Colombo and the costs of various pollution control interventions. As far as we are aware, this is one of very few studies which has taken into account the effect of both PM_{10} and $PM_{2.5}$ in estimating the potential health damage of auto-diesel emissions. The study begins with an analysis of structural changes in vehicle population and auto-fuel consumption in Sri Lanka. This is followed by an assessment of ambient air quality levels in Colombo based on both sample observations and statistical estimation methodologies. The estimates reveal that diesel vehicles account for about 89 per cent of PM_{10} emissions in Colombo. The estimated health damage is in the region of Rs. 22 to 17 billion per annum based on high and low impact scenarios. Of the various pollution control measures, reduction of the price differential between petrol and diesel ranks as the most beneficial intervention followed by inspection and maintenance programs. In overall terms, policy-oriented pollution control options take priority over technical solutions in reducing potential health damage due to auto-diesel emissions.

1. INTRODUCTION

The vehicle population in Sri Lanka significantly increased during the post-liberalization period which commenced in 1977. The high growth of diesel-powered vehicles and the high rate of auto-diesel consumption were clearly noticeable throughout the 1990s. This was attributed to the high economic growth, auto-fuel pricing policy (on petrol and diesel) and fiscal policy on vehicle imports. A distinctive feature of auto-fuel (petrol and diesel) pricing in Sri Lanka is the significant price differential between petrol and diesel. In fact, in the 1990s, Sri Lanka was the only country which maintained the highest disparity between petrol and diesel prices. The discriminatory pricing policies adopted by successive governments over the past four decades have been highly favourable towards diesel users. Similarly, the fiscal policy on vehicle imports has also been highly discriminatory against certain categories of vehicles. Furthermore, the road user charges applicable to different categories of vehicles do not fully capture road damage costs. These distortions have led to high growth of diesel-powered vehicles which use low quality diesel (i.e., 0.8 per cent of sulfur). One of the major environmental problems associated with this development is the deterioration of ambient air quality levels with respect to particulate matter of size 2.5 and 10 microns ($PM_{2.5}$ and PM_{10}). Particulate matter is a major air pollutant measured in terms of microns (μm) in diameter. Particles smaller than 10 microns (PM_{10}) are called inhalable particulate matter and those smaller than 2.5 microns ($PM_{2.5}$) are called fine or respirable particulate matter.

The primary objectives of the present study are:

a) to estimate the health impact of auto-diesel emissions in the city of Colombo, and

b) to compare the costs and benefits of various policy options in controlling auto-diesel emissions.

This paper is organized into six main sections. After the introduction (Section 1), Section 2 deals with the growth of vehicle population and auto-fuel consumption in Sri Lanka paying particular attention to the growth of diesel-powered vehicles and auto-diesel consumption. Section 3 presents an assessment of air quality levels in Colombo while Section 4 deals with the impacts and valuation of auto-diesel emissions. Section 5 examines the costs and benefits of various pollution control measures and Section 6 provides conclusions. The exchange rate used in the analysis is US$ 1= 100.00 Sri Lankan Rupees (Rs).

2. BACKGROUND INFORMATION

This section presents a brief account of the growth of diesel-powered vehicles and vehicular emissions due to auto-diesel consumption.

2.1 Growth of diesel-powered vehicles and auto-diesel consumption

The structural changes in vehicle population are analyzed in Table 1 and the evidence reveals that the relative share of motorcycles (MCs) compared to other vehicle categories in the vehicle population increased from 13 to 44 per cent between 1960 and 2004. It also indicates that the relative share of petrol-powered cars, dual-purpose (D/P) vehicles[1], buses and lorries reduced from 77 per cent in 1960 to 18 per cent in 2004. During this period, the relative share of petrol-powered vehicles reduced from 93 to 74 per cent. In contrast, the relative share of diesel-powered vehicles increased from 8 per cent in 1960 to 26 per cent in 2004. In fact, without MCs, diesel-powered vehicles accounted for about 45 per cent of total vehicle population.

[1] Refers to light duty vehicles or four-wheeled drive vehicles, jeeps, pick-ups and station wagons.

Table 1. Structure of vehicle population (in '000s)

Vehicle type	1960	%	1980	%	2004	%
Motor Cycles (P)	17.8	13.2	80.2	23.2	756.0	43.5
Cars (P)	78.2	58.0	112.0	32.4	278.3	16.0
Dual Purpose (P)	0	0	2.2	0.6	25.9	1.5
Buses & Lorries (P)	26.5	19.6	36.8	10.7	-	-
Land vehicles[2] (P)	2.3	1.7	6.8	2.0	3.7	0.2
3-Wheelers (P)	0	0	0	0	210.9	12.2
Total (P)	124.8	92. 2	238.0	68.9	1274.8	73.4
Cars (D)	0	0	2.1	0.6	34.2	2.0
Dual Purpose (D)	0	0	10.0	2.9	187.8	10.8
Buses (D)	3.5	2.6	16.4	4.7	42.9	2.5
Lorries (D)	6.1	4.5	27.9	8.1	111.6	6.4
Land vehicles (D)	1.0	0.7	31.6	9.2	82.5	4.7
3-Wheelers (D)	0	0	19.3	5.6	4.1	0.2
Total (D)	10.6	7.8	107.3	31.1	463.1	26.6
Total P & D	135.4	100.0	345.3	100.0	1737.9	100.0

Sources of basic data: Kumarage (2000) and Registrar of Motor Vehicles

Notes: D = Diesel, P = Petrol

An analysis of the growth of vehicle population in Sri Lanka from 1960 to 2004 reveals that both petrol and diesel vehicles recorded a rapid increase immediately after the introduction of liberalized economic policies in 1977 (Figure 1). However, it is important to note that the high growth of petrol-powered vehicles (PVP) has been heavily influenced by the phenomenal growth of MCs. Among diesel-powered vehicles (DVP), D/Ps appear to have recorded the highest growth throughout the 1990s. It is also interesting to note that except for MCs, PVPs grew at five per cent while DVPs grew at about six per cent per annum, slightly above real GDP growth. In contrast, D/P vehicles grew at a rate of 8-9 per cent per annum.

The demand for vehicles in Sri Lanka is entirely met by imports comprising used vehicles (75%) and brand new vehicles (25%).[3] The latter includes imports of brand new cars, light vehicles, and body kits and chassis. The explanation for the growth and structural changes in vehicle population in Sri Lanka over the past two decades is rather complex. In broad terms, they could be attributed to a wide range of factors such as a distorted duty structure on vehicle imports, duty concessions to

[2] Refers to all four-wheeled and two-wheeled tractors.

[3] Micro Manufacturers Pt. Ltd. started assembly of cars and small vans on small scale only in 2004.

selected user groups (e.g., politicians, doctors and civil servants) and pricing policies on road-fuel. For example, diesel-powered vehicles are subject to excise duties in addition to import duties. But the age limit applicable to reconditioned vehicles is three years for petrol vehicles as opposed to five years for diesel vehicles. As a result, the effective tax to be paid at the point of import for a five-year old diesel vehicle is much lower than that for a three-year old petrol vehicle. Continued practice of this policy led to a steady shift from petrol cars and vans to diesel-powered dual-purpose vehicles in the 1990s.

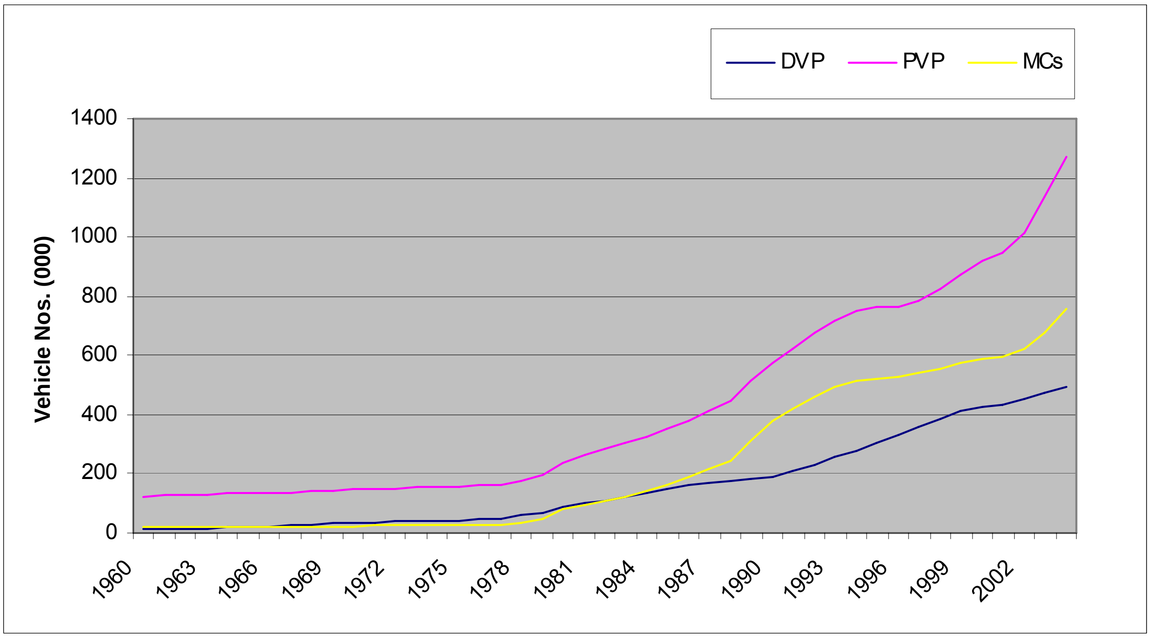

Figure 1. Growth of vehicle population (1960-2002)

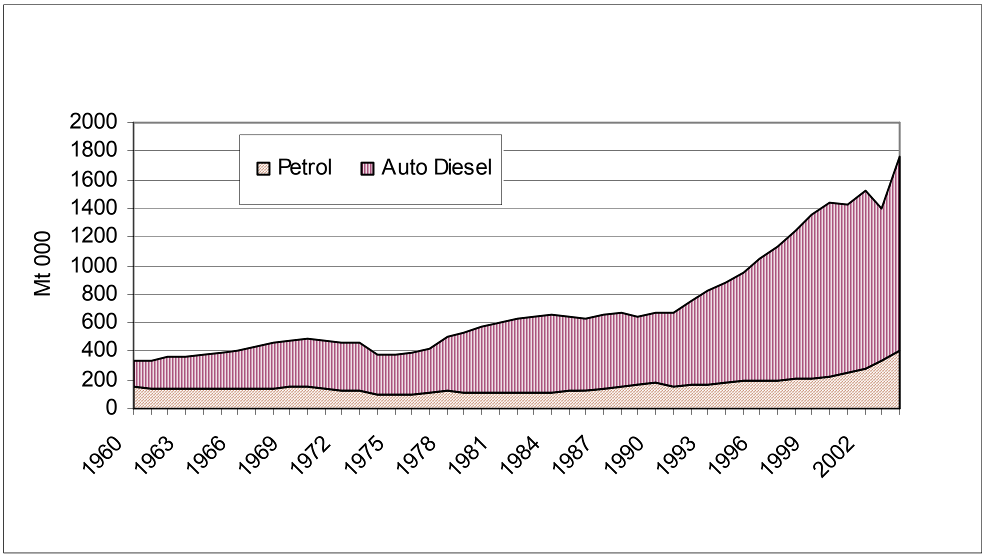

Figure 2. Fuel consumption by transport sector (1960-2002)

In response to structural changes in vehicle population, auto-fuel consumption patterns have also changed quite significantly over the past one and half decades (Figure 2). More specifically, the consumption of auto-diesel recorded a significant increase during the post-liberalization period as compared with other sub-sectors. For example, in 2001, the transport sector accounted for about 96.2 per cent of diesel consumption while the rest was shared by industrial, commercial and power generation sub-sectors. Similarly, the per capita diesel consumption by the transport sector increased from 37 litres in 1980 to 83 litres in 2004, against an increase of 10 litres to 27 litres per capita petrol consumption during the same period. Work by Chandrasiri (1999 & 2006) reveals the cross substitution effect between petrol and diesel and contributory factors relating to overall changes in auto-fuel consumption.

Sri Lanka imports its entire requirement of petroleum fuels. Up to 2002, the Ceylon Petroleum Corporation (CPC), a state-controlled monopoly, functioned as the sole institution responsible for the import and distribution of auto-fuel for the transportation sector. It has refinery capacity to meet the total demand for petrol and 35 per cent of total auto-diesel demand. The remaining 65 per cent of auto-diesel demand is met by direct imports by the CPC. With the liberalization of the petroleum market in July 2003, the Indian Oil Corporation (IOC) entered the petroleum retail market with 100 filling stations. The government is keen in further liberalizing the petroleum market.

2.1.1 Vehicular emissions due to auto-diesel consumption

Diesel engine exhaust emissions contain numerous chemical compounds partly as gas and partly as particles. The major gaseous products of combustion include carbon dioxide, oxygen, nitrogen, water vapour, carbon monoxide, sulfur dioxide, nitrogen oxide, hydrocarbons and their derivatives, benzene, toluene and polycyclic aromatic hydrocarbons (PAH). The main feature of diesel vehicle exhaust emissions is that they result in particles at a rate of about 20 times greater per litre consumed than petrol-fuelled vehicles (WHO, 1996). These particles from diesel emissions contain carbon, organic compounds absorbed from fuel, sulphates from fuel, sulfur, and traces of metallic components. Particles range between 0.02 – 0.5 um and can aggregate and form larger particles up to a maximum of 30 um. The health effects of diesel are similar to other air pollutants and are a result of the compounds released during combustion (Pandiya et al., 2002). Respiratory illnesses are the predominant problem encountered and recently there has been evidence of diesel fumes resulting in lung cancer (Bofetta et al., 2001).

As revealed by the emission inventory prepared by the Metropolitan Environment Implementation Program (MEIP) in 1992, the transport sector is the biggest contributor to air pollution in Colombo while the emissions from the other sectors are relatively low except for sulfur dioxide (SO_2) (Table 2). The inventorization is based on published information on fuel consumption, vehicle registration, industrial production, and population in Sri Lanka. It is also based on emission factors given by the World Health Organization (WHO) and the U.S. Environmental Protection Agency (USEPA) with certain adjustment to suit Sri Lankan conditions. Evidence from subsequent studies further confirms the dominance of vehicles as a source of suspended particular matter (SPM). For example, the Baseline Study for Air Pollution in Sri Lanka (CEA, 1999) revealed that within the urban areas such as Colombo, SPM is predominantly due to vehicular emissions especially from diesel vehicles. Given the high growth of vehicle population and high consumption rates of auto-diesel, we expect the relative magnitude of air pollution caused by the transport sector to be at the same level or even higher than that of 1992.

A recent study on vehicle emissions in Sri Lanka also reported that diesel and two-stroke petrol vehicles together contribute to over 80 per cent of particulate matter and smoke (USAID/US-AEP, 2005). From an inter-sectoral comparative perspective, the growth of the industrial sector between 1993 and 2004 was around six per cent per annum[4] as against the growth of petrol and diesel vehicles at 9 and 17 per cent per annum respectively. Petrol and diesel consumption also recorded average growth rates of 7 and 11 per cent per annum during the same period.

Table 2. Estimated emissions from petroleum combustion sources

Source	SPM	SO_2	NO_x	HC	CO
Transport	88.2	4.77	81.6	99.78	99.9
Industry	9.2	93.59	17.1	<1	<1
Power & Commercial	<1	<1	<1	<1	<1
Households	2.5	<1	<1	<1	<1
Total in per centage	100	100	100	100	100
Total in ton/year	3,913	10,467	7,268	38,446	199,843

Source: MEIP (1992)

Notes:

SPM = Suspended particulate matter

SO_2 = Sulfur dioxide

NO_x = Nitrogen oxide

HC = Hydrocarbon

CO = Carbon monoxide

In 2003, the National Building Research Organization (NBRO, 2003) reported a significant reduction in total ambient lead levels with the complete banning of leaded petrol in 1997. Accordingly, total ambient lead levels reduced by more than 90 per cent between 1993 and 2003. For example, the average concentration of ambient total lead ($\mu g/m^3$) reduced from 206.82 in October 1993 to 28.81 in December 2002. Another data set compiled by the NBRO (2003) covering three monitoring stations[5] in Colombo also revealed significant reductions in lead levels from May to December, 2002. Similarly, work by Wijayamuni (2003) showed a marked decrease in blood lead levels (BLL) in Colombo over a period of 10 years and the current BLL is well within WHO safety limits. From this evidence, one can safely identify diesel-powered vehicles as the main source of local air emissions in Colombo.

The other pollutants affecting ambient air quality levels in Colombo include SO_2, particulate matter (PM_{10} and $PM_{2.5}$), NO_2, CO, and ozone. Of these pollutants, particulate matter has been identified to be of greatest concern to public health. For

[4] This is based on industrial output. The growth rate based on employment was 5.7 per cent per annum from 1993 to 2003.

[5] Three monitoring stations: a) the Fort Railway Station (most polluted station), b) Meteorological Dept., Colombo 7 (background station) and c) NBRO, Colombo 5 (base station).

example, the findings of the Continuous Air Quality Monitoring Program (CAMP)[6] initiated by the NBRO clearly identified particulate matter as a major pollutant in Colombo. The high correlation between total suspended particles (TSP) levels and traffic density in Colombo observed by Mathes et. al., (1993) further confirmed this. It also revealed that TSP levels in sample locations of Colombo were far above the standards recommended by WHO (Chandrasiri, 1999).

2.1.2 Relative contribution of auto-diesel to PM

In order to asses the relative magnitude of auto-diesel emissions in total atmospheric pollution, the total stock of emissions from vehicle combustion was estimated using the formula below (1). As per Lvovsky et al. (2000), this was estimated based on three primary pollutants: a) coarse and fine particulates (PM_{10} and $PM_{2..5}$), b) sulfur dioxide (SO_2) and c) nitrogen oxide (NO_2).

$$\text{Emission} = \sum (\text{EFabc X Activity abc}) \qquad (1)$$

where: EF = emission factor[7]

Activity = amount of energy consumed or distance travelled for a given mobile source activity

a = fuel type

b = vehicle type

c = emission control

The estimates reveal that diesel-driven vehicles account for about 96 and 89 per cent of SO_2 and PM_{10} emissions respectively (Table 3). According to the estimates prepared by the Air Resources Management Centre (ARMC, 2003c), diesel engine vehicles account for about 79 per cent of total PM_{10} emissions. It also reported that diesel-powered D/Ps and heavy buses and trucks accounted for about 81 per cent of auto-diesel PM_{10} emissions while our estimates indicate this ratio to be in the region of 90 per cent. As noted above in Table 1, these vehicles account for about 20 per cent of the total vehicle population, but accounts for approximately 80 per cent of total PM_{10} emissions. Considering the relative contribution of the transport sector to total SPM levels in Colombo (Table 2) and the evidence given in Table 3, we assume the relative share of auto-diesel emissions to be in the region of 78 per cent of total health damage due to PM_{10} and $PM_{2.5}$.

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[6] For details on Phase I and II of the CAMP, see http://www.nsf.ac.lk/nbro/enviro

[7] This is based on emission factors given in Faiz. et al., (1996) and World Bank (1997). The latter is more relevant to Sri Lanka as it captures the experience of Greater Mumbai in India.

Table 3. Estimated pollution levels in Colombo (in tons/year, 2004)

Vehicle type	Emission factors (grams/km)			Colombo VP 2004	km/ year	Emission (tons/year)		
	NO_2	SO_2	PM_{10}			NO_2	SO_2	PM_{10}
MCs – 2S (P)	0.022	0.02	0.206	120969	5533	14.73	13.39	137.88
MCs – 4S (P)	0.022	0.02	0.048	257059.5	5171	29.24	26.59	63.80
Cars (P)	0.005	0.1	0.1	139148	8274	5.76	115.12	115.13
D/Ps (P)	0.006	0.08	0.12	12937.5	5468	0.42	5.66	8.49
3-Wheelers (P)	0.022	0	0.206	105473	19676	45.66	0.00	427.51
Total (P)						95.81	160.76	**752.81**
Cars (D)	0.01	0.39	0.33	17112.5	16759	2.87	111.85	172.07
D/Ps (D)	0.017	0.39	0.37	93918	14684	23.44	537.85	1241.18
Buses (D)	0.03	1.5	2	21439	40117	25.80	1290.10	1720.14
Lorries (D)	0.03	1.5	2	55807.5	22394	37.49	1874.63	2499.51
Land vehicles (D)	0.03	0.39	2	41252.0	3652	6.41	83.35	427.43
Total (D)						96.01	3897.78	**6060.33**
Total P & D						191.82	4058.54	**6813.14**
% of diesel vehicles						50	96	**89**

Sources: World Bank (1997) and Faiz et al., (1996)

Notes:

1) These estimates are based on the assumption that 50% of the total vehicle population operates in Colombo

2) MC = motorcycles 2S = two-stroke 4S = four-stroke D = diesel P = petrol
D/Ps = dual-purpose vehicles VP = vehicle population

We accept these figures as reasonable estimates of particulate matter emissions from petrol- and diesel-powered vehicles. Recent pilot studies conducted by the Central Environment Authority (CEA) revealed that there is no significant contribution to PM_{10} or $PM_{2.5}$ from petrol-powered vehicles due mainly to the following facts:

1. Petrol-powered vehicles which are older than 20 years have gone out of the active fleet.

2. The active petrol fleet consists mostly of vehicles less than five years old, having modern technology. Special attention has been given to these modern gasoline vehicles to reduce PM_{10} or $PM_{2.5}$ emissions in accordance with the rules and regulations of the country of manufacture.

3. Sri Lanka has totally phased out leaded petrol which was the main contributor of PM_{10} and $PM_{2.5}$ as lead particulates.

With respect to petrol-powered vehicles, two stroke three-wheelers and MCs contribute significantly to the emission of PM_{10} and PM $_{2.5}$.

3. AIR QUALITY ASSESSMENT

This section of the paper deals with air quality levels in the city of Colombo based on air quality data collected by the CEA through its Air Quality Monitoring Station located at Colombo Fort. The National Ambient Air Quality Standards for Sri Lanka were gazetted in 1994 by the then Ministry of Environment under the National Environmental Act (NEA) by taking into consideration WHO guidelines and standards prevailing in other countries (Table 4). The air quality statistics compiled by the CEA since 1997 covering different pollutants are analyzed below.

3.1 Sulfur dioxide

As can be seen from Figures 3 and 4, the sulfur dioxide concentration shows an increasing trend from 1997 to 2001 in both the monthly mean sulfur dioxide levels as well as the maximum one-hourly values together with a regular seasonal variation. Maximum values occur during the December-February period, a time of the year characterized by dry weather resulting from the north-east monsoon. This rising trend is most likely caused by increasing numbers of diesel-powered motor vehicles operating in the central city area and particularly in the main road that passes the station. This road also suffers from regular traffic congestion resulting in elevated levels of all pollutants. There is a marked seasonal trend (during the December-February period) in occurrences of high concentrations (exceeding the mean) and also an upward trend in the number of such occurrences.

3.2 Nitrogen dioxide

Nitrogen dioxide levels show a similar seasonal trend as sulfur dioxide (Figure 5) although these are still well below standard levels. This too suggests that nitrogen dioxide levels are area-based, closely linked to increases in vehicular movements in Colombo City and are expected to increase further as the numbers of vehicles increase.

3.3 Carbon monoxide

Carbon monoxide levels show a decreasing trend in monthly mean values from 1997 to 2001 (Figure 6). This may be due in part to an improvement in the quality of the vehicle fleet by the importation of newer, better quality vehicles as there have not been any major changes in traffic flows in the vicinity of the monitoring station.

3.4 Particulate matter (PM_{10})

Particulate matter (PM_{10}) has remained fairly consistent over the period 1998 to 2001 with the 24-hour (USEPA) standard being exceeded on only one occasion. While the 24-hour (USEPA) standard is rarely exceeded, the annual mean has exceeded the USEPA standard by around 50 per cent in each of the years suggesting a consistent background level of particulates in the air, indicating motor vehicles as the main causal factor. The levels do not, however, exceed the National Ambient Air Quality Standard of 100ug/m3 (Fig. 8).[8]

Table 4. Sri Lanka national ambient air quality standards

Pollutant	Averaging Period	Maximum permissible level	
		ppm	**mg/m^3**
Carbon Monoxide	8hr	.9	
	1hr	.26	
	Annual	.50	
Nitrogen Dioxide	Annual*	0.053	
	8hr	0.08	
	1hr	0.12	
Sulfur Dioxide	Annual *	0.03	
	8hr	0.05	
	1hr	0.08	
Ozone	1hr	0.10	
Lead	24hr		0.0005
	Annual		0.002
Suspended Particulate Matter (Sri Lanka Standard)	Annual		0.10
	24hr		0.30
	8hr		0.35
	3hr		0.45
	1hr		0.50
PM_{10}	Annual*		50 ug/m^3
$PM_{2.5}$	Annual*		15 ug/m^3

Sources: National Environmental Act (1994) and USEPA (1999)

Note: ***** refers to USEPA standards. ppm = parts per million

[8] The air quality monitoring station at Fort in Colombo does not measure Total Suspended Particulate Matter (TSP) but PM_{10} is measured as it is more relevant to human health.

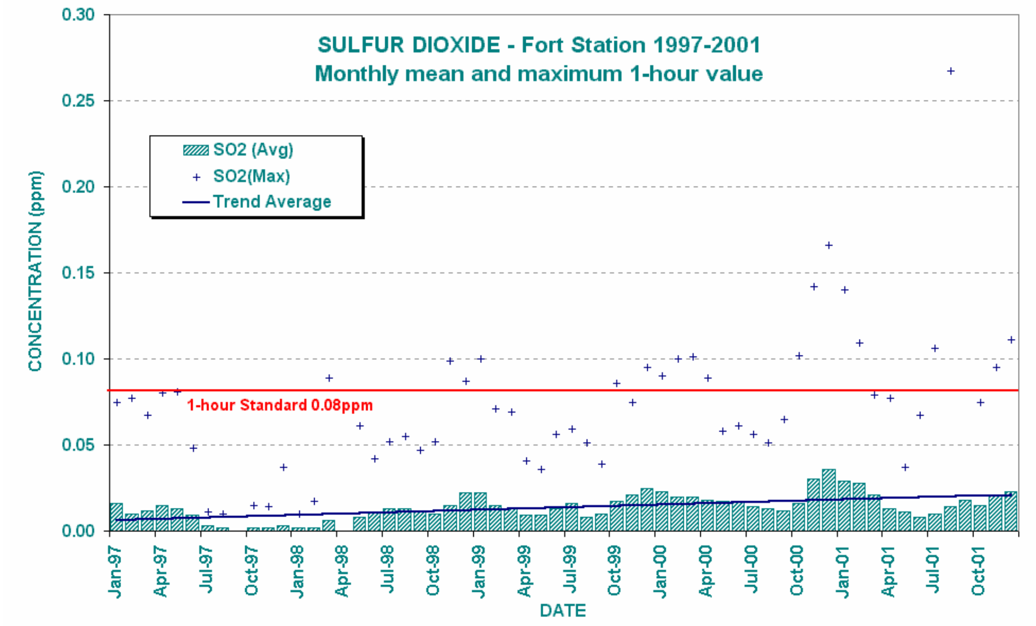


Figure 3. Sulfur dioxide – mean values (Fort Station, 1997 – 2001)

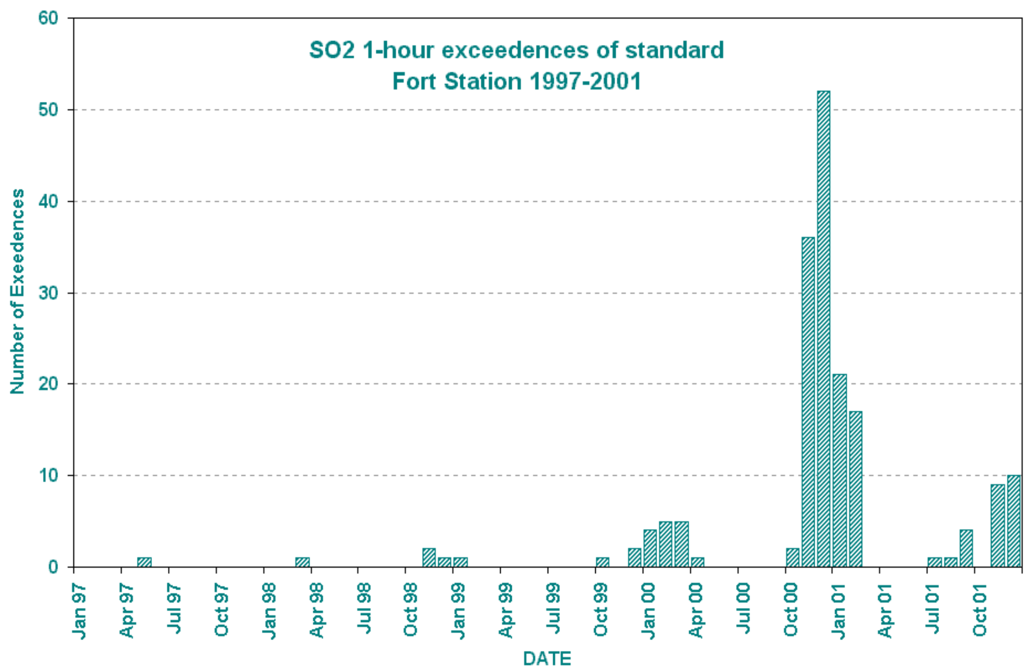


Figure 4. Sulfur dioxide – exceedences of standard values (Fort Station, 1997-2001)

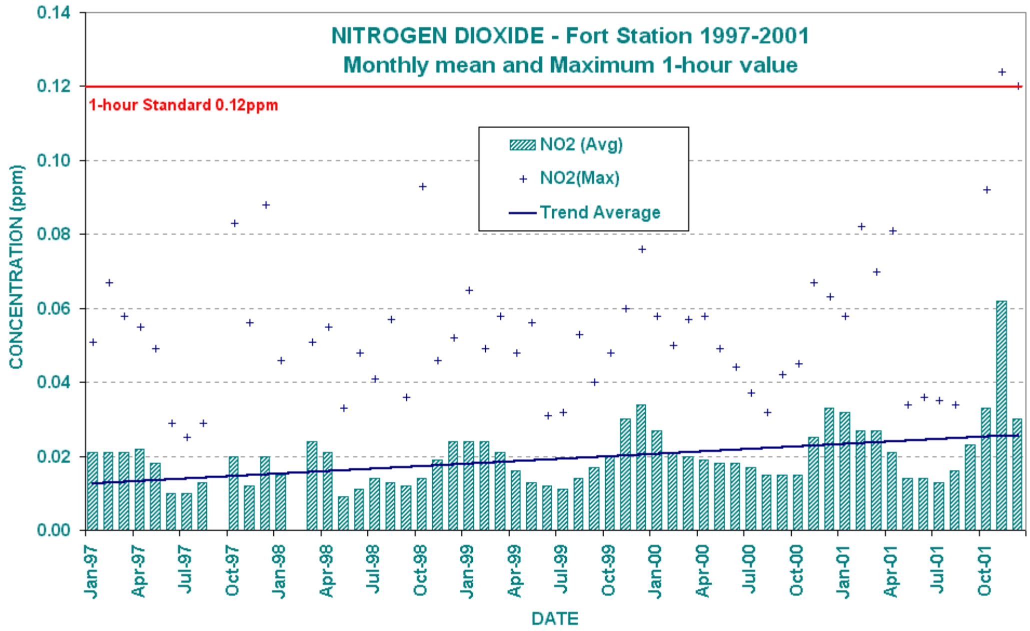


Figure 5. Nitrogen dioxide (Fort Station, 1997-2001)

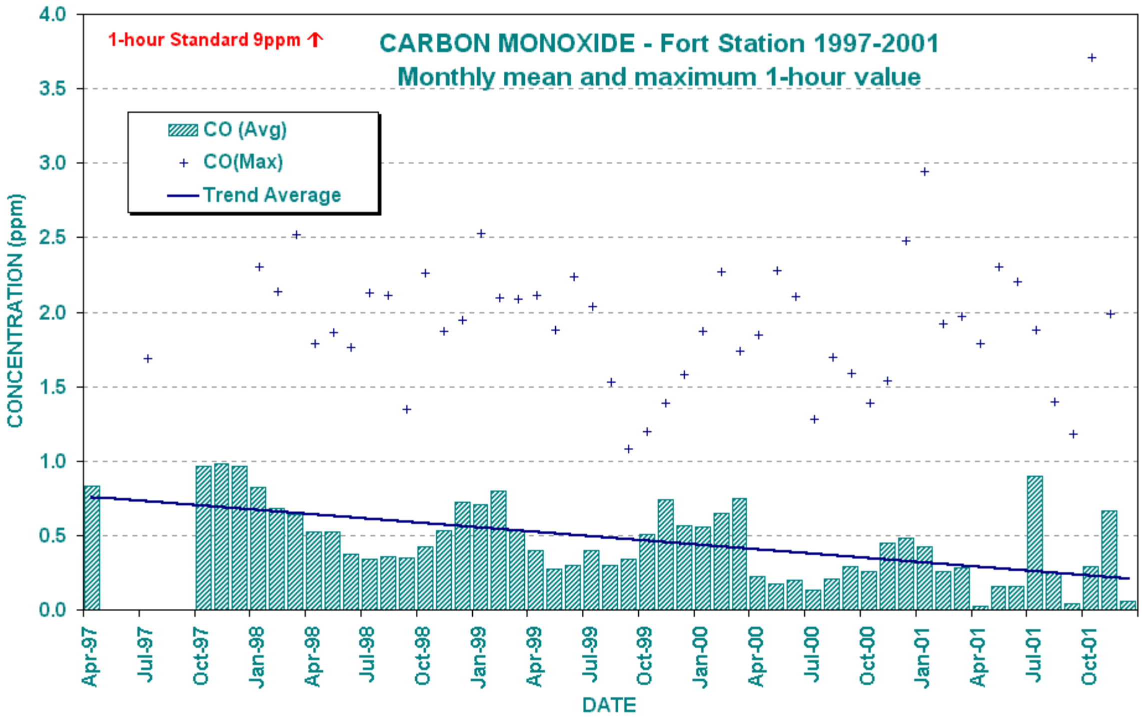


Figure 6. Carbon monoxide (Fort Station, 1997- 2001)

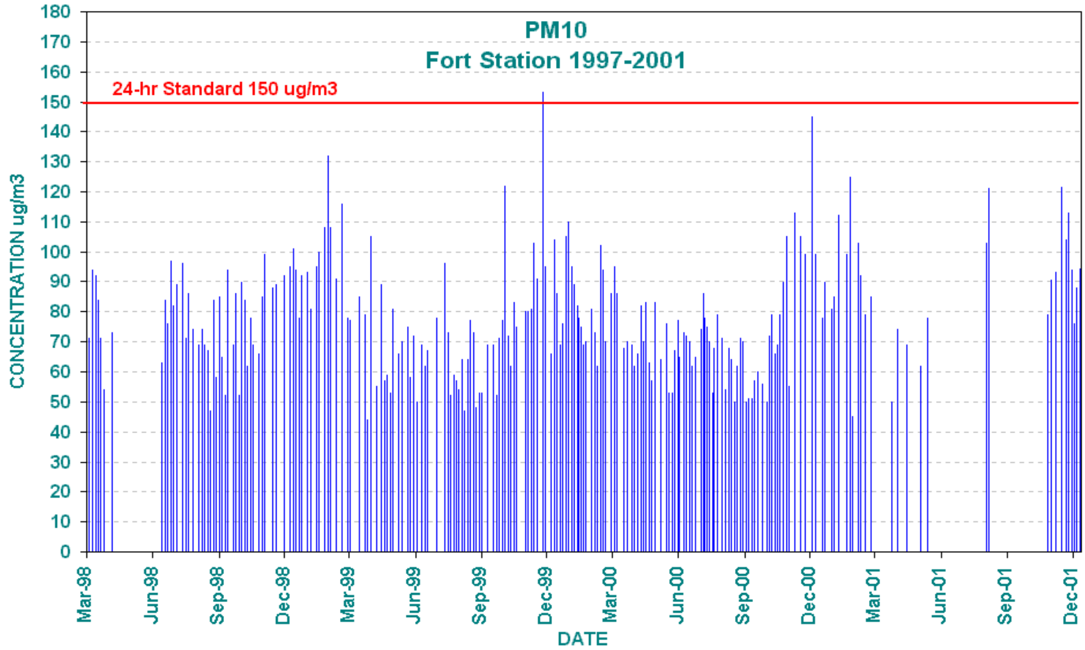


Figure 7. PM_{10} (Fort Station, 1997 – 2001)

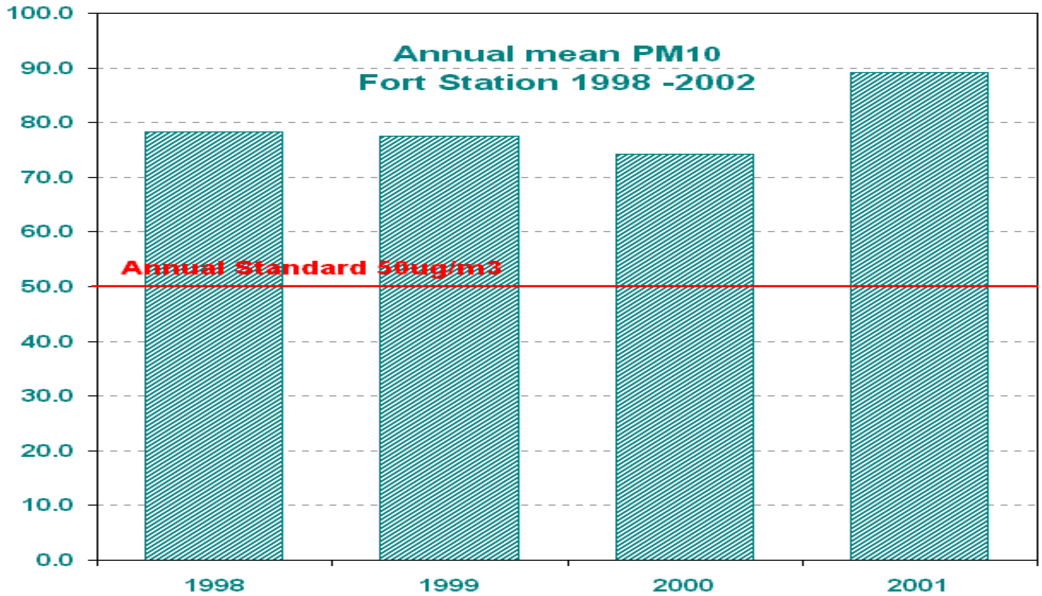


Figure 8. Annual mean PM_{10} (Fort Station, 1998 – 2002)

The analysis given in Table 5 is an attempt to compare and contrast air quality levels in Colombo against recommended standards by USEPA. The evidence reveals that three major pollutants, CO, SO_2 and NO_2, have not exceeded the recommended standards over the past eight years. In contrast, both PM_{10} and $PM_{2.5}$ have exceeded the recommended standards over the past several years. In the present study, city specific concentration of $PM_{2.5}$ was estimated as a fixed proportion of PM_{10}. Existing empirical work indicates that the ratio of $PM_{2.5}$ to PM_{10} ranges from 0.5 to 0.8 in many urban areas of developed economies. In the case of developing economies, limited evidence suggests similar ratios. In the case of China, for example, $PM_{2.5}$:PM_{10} is in the range of 0.51 to 0.72 for urban locations (Cohen et al., 2003). Therefore, we assume a proportion of 0.625 of PM_{10} in estimating $PM_{2.5}$ pollution levels (WHO, 1996).

Table 5. Status of auto-diesel related pollutants in Colombo

Pollutant	Unit	Annual average 1997-2004*	Maximum permissible level
CO	ppm	0.438	0.5
SO_2,	ppm	0.0142	0.03
NO_2	ppm	0.0198	0.053***
O_3	ppm	0.0053	0.10
PM_{10}	ug/m^3	78.14	50.0***
$PM_{2.5}$	ug/m^3	48.83**	15.0***

Source: CEA (1994) and USEPA (1999)

Notes:

1) * = Data for 2002 and 2003 are based on data collected only for four months as the air quality monitoring station at the fort was closed most of the time due to power cuts, repairs and upgrading of the analyzers.

2) ** = $PM_{2.5}$ figures are based on the assumed proportion of 0.625 of PM_{10}.

3) *** = USEPA standards

From the above analysis, it is clear that the annual average level of PM_{10} from 1997 to 2004 does not exceed the national air quality standard of 100ug/m3. However, it is considerably higher than the US PM ambient air quality standard of 50 ugm^3. Hence, this analysis aims to examine the costs and benefits of various pollution control options if Sri Lanka were to implement US PM_{10} standards. It is also important to note that the pre-1997 WHO guidelines for annual average levels of PM_{10} were 40-60 ug/m^3. The standards for PM_{10} recommended by the Organization for Economic Corporation and Development (OECD) range between 40-50 ug/m^3 (annual average). The US and the European Union are currently considering the adoption of stricter standards (Lvovsky et al., 2000).

The relevance of threshold values for particulate matter is an issue with direct relevance to the present study. In estimating health damage, the use of threshold values for different health endpoints implies that there is no health risk below the threshold. In contrast, there is evidence that, at least for particulate matter, not only is there no threshold, but the PM coefficient is actually larger at lower levels of PM and smaller at higher levels (Akeson et al., 2000). In 1997, WHO discontinued its threshold level guidelines for particulates after observing the evidence that adverse health effects occurred even at much lower levels of exposure. Thus, health damage estimates based on threshold values could be considered as reflective of minimum damage costs associated with vehicular emissions.

Another important point deserving emphasis at this stage of the study is examining whether air quality monitoring data generated by the Colombo Fort Station gives a true picture of the air quality levels in the city and its environs. Many of the earlier studies including Mathes et al., (1993) found excessive pollutant concentrations at Thunmulla, Maradana, and the Eye Hospital with regular exceedences of PM_{10}. These are three different locations within Colombo City with high traffic congestion. A recent study by the Public Interest Law Foundation found that both $PM_{2.5}$ and PM_{10} levels exceeded the recommended standards more than 90 per cent of the time at the Thursten road area. Recent work on remote sensing of vehicle emissions in Sri Lanka stated that "In Colombo, the largest metropolitan area in the country, the observed total suspended particle (TSP) level is higher than that recommended by WHO" (USAID/US-AEP, 2005). It covered two different site locations in Colombo City i.e., Ward place and in front of Hayleys.[9]

4. IMPACTS AND VALUATION

This section deals with the health impacts and economic valuation of auto-diesel emissions in Colombo. The physical impact of auto-diesel emissions is based on the application of the concentration-response (CR) function method adopted by Akeson et al. (2000) for diesel-powered vehicles. The CR function employed to estimate the change in health end points is given in equations 2 and 3.

$$\Delta Change\ in\ Mortality = -\left\lfloor y_0 . (e^{-\beta . \Delta PM_{2..5}} - 1) \right\rfloor \cdot pop \qquad (2)$$

where

y_0 = country level non-trauma mortality rate per person aged 30 and older

β = $PM_{2.5}$ coefficient

$\Delta PM_{2.5}$ = Change in annual mean of $PM_{2.5}$ concentrations

pop = exposure groups

$$\Delta Change\ in\ Morbidity = -\left\lfloor y_0 . (e^{-\beta . \Delta PM_i} - 1) \right\rfloor \cdot pop \qquad (3)$$

where

y_0 = country level morbidity rates for different illnesses (e.g., pneumonia, asthma and acute respiratory tract infections)

β = ΔPM_{10} coefficient for different illnesses

[9] Refers to two other sample locations within Colombo City but away from Colombo Fort. The purpose is to demonstrate the deteriorating air quality levels in different parts of Colombo City.

ΔPM_i = change in annual mean of $PM_{2.5}$ or PM_{10} concentrations

pop = exposure groups

As noted in Section 3 on air quality assessment, the existing data sets on ambient air quality in Colombo tend to underestimate the actual health damage. Hence, in the application of the CR function for Colombo, the identification of exposure groups has to be based on several other criteria such as traffic density,[10] air quality data compiled by other institutions in the mid-1990s, and concentration of business and administrative centres in the city of Colombo. In terms of land, Colombo City covers 37.32 sq km and accommodates a total population of about 642,163. In administrative terms, this covers 47 wards (a ward is a standard term used by the census authorities in defining census blocks) representing two Divisional Secretariat (DS) Divisions a) Colombo DS Division and b) Thimbirigasyaya DS Division. In addition, about 120,000 persons come to Colombo on daily basis for business purposes.

Given the highly diverse nature of economic activities and the unplanned character of the city of Colombo, clear identification of relevant exposure groups (POP) for health damage estimates is rather difficult. Thus, in the application of POP, we propose to assess the impact of auto-diesel emissions based on three scenarios; a) high, b) middle, and c) low case scenarios. The high case scenario is based on the assumption that the total population in Colombo is exposed to high pollution concentration and hence include the entire 47 census wards. However, the low case scenario is limited only to direct exposure groups selected on the basis of location specific criteria (i.e., traffic intersections, concentration of industrial and commercial activities, etc.) and represents only 35 wards. The middle case scenario covers the low case scenario plus other potential exposure groups such as those living in highly residential areas, but working in the city centre. It covers 43 census wards.

As stated earlier, the computation of ΔPM_{10} and $\Delta PM_{2.5}$ is based on USEPA air quality standards (annual averages) i.e., 50 ug/m^3 and 15 ug/m^3 for PM_{10} and $PM_{2.5}$ respectively. Use of annual average pollution concentration data in estimating health damage is well established in past literature including some recent work by Lvovsky et al., (2000) and the World Bank (2005). We assume that the risks of morbidity and mortality due to PM increase linearly over and above the recommended air quality standards. In estimating the health damage, we also assume a single level of pollution for the whole city of Colombo.

The CR function coefficients (β) employed in the present estimates, however, are based on empirical evidence in the literature. More specifically, this refers to the application of CR functions employed by the Akeson et al. (2000) on diesel fuel based on earlier work by Krewski et. al. (2000) on mortality; Samet et al. (2000) on pneumonia; Sheppared et al. (1999) on asthma; Dockery et al. (1996) on acute bronchitis; and Schwartz et al. (1994) on lower respiratory illnesses.

[10] In terms of vehicle population, Colombo Metropolitan accounts for about 50 per cent of the registered vehicle population. An additional 10 per cent come to Colombo daily from neighbouring regions.

In order to translate physical damage estimates into monetary values, a separate study on the costs of illnesses (COI) was carried out covering both in-patients and out-patients in Colombo. It covers the following diseases which have been recognized as illnesses caused or exacerbated by auto-diesel emissions. The selection was based on the availability of data on the diseases and previous studies which have correlated the number of new cases arising as a result of an increase in units of pollutants.

1. Asthma in adults and children

2. Pneumonia in adults

3. Lower respiratory tract infection in children

4. Acute respiratory infection (excluding pneumonia) in children and adults.

Hospital data relating to the above diseases is limited by the fact that routine data collection is done only on patients admitted to public hospitals. Thus, there is little information on those admitted to private hospitals and those utilizing the out-patient dispensaries (OPD) and clinics. However, asthma admissions to state hospitals have shown a steady increase over the last few years. An increase of almost 2.5-fold is seen from 1985 (395 cases per 100,000 people) to 2001 (953.5 per 100,000) (Ministry of Health, 2002). Sri Lanka's Ten-Year Health Plan assumes a 10 per cent ratio of asthma patients in the country. This may be the result of a combination of factors: more people getting asthma, better diagnosis of the illness, and patient preference for state sector care. Moreover, the fact that the number of deaths from asthma has increased indicates that the severity and possibly also the prevalence of the disease have increased. Country-wide and Colombo-specific details on the spread of the above illnesses are given in Appendices 1 and 2 respectively.

4.1 COI survey methodology

The costs of illnesses include the cost of investigations, drug treatment and personnel cost, doctor's time and non-medical costs such as costs incurred by the patient for food and accommodation.

Ethical approval was obtained from the Faculty of Medicine, University of Colombo, to carry out a survey on people suffering from asthma, pneumonia and respiratory tract infections with a view to estimating the different cost components for each illness. A structured questionnaire was designed to gather information on the age, sex, and occupation of the patient, the list of investigations and the list of drugs prescribed by the doctors.

The sample consisted of 213 patients (Table 6). In terms of institutions, the sample covers the public sector, private sector and general practitioners (GPs). The GP survey was conducted by randomly choosing a sample of 22 general practitioners in the southern part of Colombo district. This area was chosen because of easy access. With a view to improving the accuracy of information, the GPs were requested to carry out a thorough diagnosis of air pollution related illnesses before selecting a patient for the survey. They were then asked to complete a questionnaire for three patients – one suffering from acute asthma, one from pneumonia and one from acute respiratory infection (excluding pneumonia).

Table 6. Sample distribution – number of patients

	NHSL		SJGH		Private hospitals (n=6)		GPs (n=22)	Total
Illness	**OPD**	**In-pts**	**Child**	**Adult**	**OPD**	**In-pts**		
Asthma	14	24	3	12	19	11	22	105
Pneumonia	-	17	-	3	9	4	20	53
Respiratory Tract Infections	-	-	22	-	11	-	22	55
Total	14	41	25	15	39	15	64	213

Notes:

NHSL = National Hospital of Sri Lanka; SJGH = Sri Jayawardenapura Government Hospital

GP = General practitioners

OPD = out-patient dispensary; In-pts = in-patients

For the survey of private hospitals, the most popular and large hospitals in Colombo City were chosen since they represented the majority of patients who sought private health care. The sample consisted of three private hospitals: Asiri, Durdans and Asha. The out-patient dispensary (OPD) medical officers of these hospitals were given a questionnaire similar to the one given to the general practitioners. Each doctor was requested to choose up to 10 consecutive patients covering each illness category specified in the survey. The ward medical officers were given a separate questionnaire to be filled in for patients who were admitted with asthma and pneumonia. The diagnosis was made by the hospital consultants. All patients having the required diagnosis were included. The data requested was similar to that requested from the out-patient dispensary.

The public hospitals selected for the survey were the National Hospital of Sri Lanka (NHSL) and the Sri Jayawardenapura Government Hospital (SJGH). The data collection in these hospitals was carried out by research assistants. The information required from in-patients was the same as for private hospitals. Research assistants visited the OPDs of these hospitals and completed questionnaires on patients referred to them by the medical officers. These patients were referred based on the clinical diagnosis of asthma, pneumonia, acute respiratory infection, and lower respiratory tract infection. Data from in-patients was collected using a standard questionnaire. The diagnosis was made by the hospital consultants. All COI patients having the required diagnosis were included. Finally, the information collected through the questionnaires was used to estimate the following cost components broken down as shown below.

1. List of drugs taken for the whole duration of the illness (including the total number of doses and duration).

2. The costs of drugs were calculated in the following manner:

   - The wholesale prices of the State Pharmaceutical Corporation (SPC) were taken for in-patients and out-patients in the state sector.

   - For the private sector, the prices of drugs in the respective hospital pharmacy were taken.

   - For GPs, the prices of the drug at SPC outlets were taken. If a propriety name was used, the price used was the respective retail price of the drug.

3. Cost of investigations

This required a list of investigations done by medical personnel during the course of the illness.

3.2 The costs of investigations were calculated in the following manner:

- Costing for the state sector was based on studies done previously (i.e., De Silva et. al., 1997).

- If any cost item was not available from past literature, an average retail price was obtained from the private hospitals and a 20 per cent reduction was used to estimate the real cost for investigations in the state sector.

- For the private sector, the prices for tests charged to the patients were taken.

- For GPs, the prices of the tests of the private sector were taken.

4. Health personnel costs

4.1 Doctors' costs: For in-patients in the state sector, the number of doctors in an average ward was multiplied by their monthly incomes and the total divided by 30 to denote the cost for a particular day. This figure was divided by the average number of patients in the ward to estimate the average cost per patient in the form of doctor's time. A similar process was used for the nurses, but other categories of employees in a ward (i.e., labour categories) were ignored in the process of cost estimation. For out-patients in the state sector, the average time spent by a doctor on a patient was assumed to be three minutes. Using the number of hours of duty done by doctors in the OPD per month and their salaries, an estimate of the consultation cost was obtained.

4.2 The cost of admission and stay in private hospitals was based on room charges while in the case of public hospitals, an average of the room charges for paying beds in Class 1 of NHSL was obtained and 10 per cent of it was used as the cost for a non-paying bed. This estimate was based on the fact that the floor area of a non-paying bed is approximately 25 per cent of a paying room, but with no attached toilet or fan.

The data developed along these lines was used to estimate the average cost per illness episode in a particular setting (i.e., in-patient and out-patient care in the state sector, in private hospitals and with GPs). In addition, the cost estimates given in Table 7 are also based on the following assumptions:

- All pneumonia patients who registered at the government OPD were admitted and given treatment. Therefore, pneumonia cost in government OPD was not calculated.
- The pneumonia cost in the government sector was calculated as (NHSL cost per person + SJGH cost per person) / 2
- The asthma cost in the government sector was calculated as (NHSL cost + SJGH adult cost + SJGH paediatric cost) / 3
- The cost of acute respiratory tract infection in government OPD was based on the costs of the following drugs given for three days: PCM, amoxicillin, and piriton. These are the commonly used drugs for this condition.

Table 7. COI estimates for the city of Colombo (Rs. per case)

Type of illness	In-patient	Out-patient
Asthma	4537	800
Pneumonia	6877	746*
Acute respiratory tract infection	-	263
Lower respiratory tract infection	3692	-

Notes:
1) * = Only in the private sector.
2) There are empty cells because for some diseases, there were only in-patients or out-patients.

4.2 Adjusted COI estimates

Theoretically, COI estimates do not take into account the individual's pain, suffering, or loss of leisure activities. Hence, COI estimates capture only lower bound measures and often seriously underestimate true willingness-to-pay (WTP) to reduce mortality and morbidity (Freeman, 1994). Work by Alberini and Krupnick (2000) reveal that the ratio of WTP to COI ranges from 1.48 to 2.26 depending on PM_{10} levels. Thus, as an alternative measure, several empirical studies (e.g., ADB, 1996) have employed an adjusted COI approach with a view to arriving at more realistic health damage estimates. For example, Shahwahid and Othman (1999) employed an adjusted COI approach in estimating the health damage of fires and haze in Malaysia. Studies which incorporate the costs of prevention of illness, pain and discomfort indicate that adjusted COI estimates exceed current COI estimates. Accordingly, we propose to multiply current COI estimates by a factor of 2 in order to arrive at adjusted COI estimates and the costs vary within a range of US$ 5.26 to US$ 137.54 per episode (Table 8). It is interesting to compare our adjusted COI estimates with WTP estimates by Alberini (1997) for Taiwan at 1992 prices. Accordingly, WTP to avoid entire episodes (cold) for 1 day and 5 days were US$ 20.45 and US$ 34.62.

If the episode is not a cold, WTP values for 1 day and 5 days were US$ 30.73 and $ 52.01.[11]

Table 8. Adjusted COI estimates for the city of Colombo (Rs./per case) - 2004

Type of illness	(Rs. per case)		(US$. per case)	
	In-patient	Out-patient	In-patient	Out-patient
Asthma	9074	1600	90.74	16.00
Pneumonia	13754	1492	137.54	14.92
Acute respiratory tract infection		526		5.26
Lower respiratory tract infection	7384		73.84	

Note: Exchange rate is US$ 1 = Rs. 100

4.3 Mortality assessment

Valuing health symptoms and risks of mortality in economic terms is controversial and complicated in the context of developing countries. Most of the existing studies aimed at estimating the value of life or injury based on data from developed countries as there is very little work relating to such situations in developing countries. An estimation of health risks based on developed country scenarios however, brings with it with several methodological problems. Most of the existing work employ the value of a statistical life (VSL) in assessing the effects of air pollution on mortality. The literature on VSL, or on willingness to pay to avoid a statistical premature death, is well established, most of the empirical work being based on the US experience. A review of the existing body of work suggests a mean VSL of US$ 3.6 million (1992) to US$ 4.8 million (1997). This is based on the evidence of 26 studies comprising five CVM studies and 21 labour market (wage-differential) studies. Its application in the context of developing countries is rather problematic due to the highly distorted character of product and factor markets. The USEPA currently uses a central VSL estimate, based primarily on labour market studies, equal to about US$ 6 million (1999) for all ages. There is also a substantial amount of work on VSL based on the human capital approach. Lvovsky et al., (2000) in their work on environmental costs of fossil fuels used the lower value of US$ 3.6 million as the basis for initiating the benefits-transfer process. In view of the wide disparity among existing VSL estimates, Lvovsky et al., (2000) argued that it is preferable to concentrate on the task of transferring WTP estimates into the context of lives lost through poor air quality in countries with different income levels.

In the present study, following the tradition of some of the recent environmental impact assessments done in Sri Lanka (Fraser Thomas, 2002), we propose to assess the health risk of mortality based on estimates by Shanmugam

[11]In addition to several symptoms covered in the assessment, the methodological procedure of Alberini and Krupnick (2000) has direct relevance to our study particularly in the application of adjusted COI methodology. For example, in collecting cost data, the respondents were asked if the illness had caused them to spend a day in bed, miss work, and lose income because of missing work, or had prevented them from going about their daily activities.

(2000). It is a study based on a multi-stage sampling procedure covering male blue-collar employees in manufacturing industries operating in Tamilnadu, a state in Southern India. Accordingly, the estimated value of statistical life is in the range of Indian Rs. 13.78 to Rs. 18.55 million or US$ 0.76 to $1.026 million at 1990 prices. For estimation purposes, we take the average value of Indian Rs. 16.165 million and estimate the VSL in Sri Lanka to be around Sri Lankan Rs. 30.57 million at 2002 prices using Purchasing Power Parity (PPP) exchange rate and necessary adjustments for inflation. Comparatively, this works out to be around 27 per cent of lower bound US VSL estimates. Moreover, it is about 62 per cent of the value used by Lvovsky et al., (2000) in their six-cities study i.e., of Mumbai, Shanghai, Manila, Bangkok, Krakow and Santiago.

4.4 Health damage estimates of PM_{10} and $PM_{2.5}$

The health damage estimates of PM_{10} and $PM_{2.5}$ both in physical and monetary terms are given in Table 9 and Appendix 3. Accordingly, mortality effects appear to vary between 712 and 550 cases per annum based on high and low impact scenarios. With respect to morbidity, the number of asthma cases is in the region of 6079 to 4698 per annum for out-patients while it is in the range of 433 to 335 in the case of in-patients. Similarly, the total number of acute respiratory tract cases (out-patients) is in the range of 932 to 720 per annum. The impact of particulate matter in monetary terms is about Rs. 22, 18 and 17 billion per annum based on the high, middle and low impact scenarios respectively, assumed in the present study (Table 10). It also reveals that $PM_{2.5}$ related health damage is of high magnitude and varies from Rs. 22 to 17 billion per annum.

Table 9. Impact of PM_{10} and $PM_{2.5}$ - 2004

PM10	**Unit**	**Scenarios**		
		High	**Middle**	**Low**
Asthma – Out patient	Cases	6079	4908	4698
	Rs. Millions	9.73	7.85	7.52
Pneumonia – In patient	Cases	47	38	36
	Rs. Millions	0.64	0.52	0.50
PM2.5				
Mortality	Persons	712	575	550
	Rs. Billions	21.8	17.6	16.8
Asthma – In patient	Cases	433	350	335
	Rs. Millions	3.93	3.17	3.04
Acute Respiratory Tract (LRT) – Out patient	Cases	932	753	720
	Rs. Millions	0.49	0.40	0.38

Source: Appendix 3

Table 10. Health damage due to PM_{10} and $PM_{2.5}$ - 2004

Particulate matter	Unit	High	Middle	Low
PM_{10}	Rs. Millions	10.37	8.37	8.01
$PM_{2.5}$	Rs. Billions	21.8	17.6	16.8
Total	Rs. Billions	21.8	17.6	16.8

Table 11. COI and adjusted COI health damage estimates - 2004

Scenarios	High	Middle	Low	High	Middle	Low
Value	Rs. Mn/t	Rs. Mn/t	Rs. Mn/t	US $/t	US $/t	US $/t
COI based						
Particulate matter	1.60	1.29	1.25	15,985	12,907	12,354
Adjusted COI based						
Particulate matter	3.20	2.58	2.47	31, 970	25,814	24,708

Notes: Rs. Mn = Rupees in millions; t = tons

Table 11 deals with cost per ton of auto-diesel emissions in Colombo both in terms of COI and adjusted COI estimates. The cost figures have been derived using total PM emissions and total health damage estimates given in Table 3 and Table 10 respectively. Accordingly, cost per ton of emissions varies from US$ 15,985 to US$ 12,354 based on COI estimates. In terms of adjusted COI estimates, cost per ton of emissions varies from US$ 31,970 to US$ 24,708 under high, middle and low case scenarios. It appears that our cost estimates are on the high side relative to some of the existing evidence in the literature. For example, PM10 health damage estimates for Colombo by ESAMP (2003) are in the region of US$ 18,000/ton for 2000 while it varied between US$ 17,790 and US$ 14,232 per ton in a six-city study by Lvovsky et. al. (2000). In addition, some of the other studies specific to Colombo have also come up with relatively low health damage estimates e.g., US$ 8500/t (Colombo-Katunayake Expressway) and US$262/t (University of Moratuwa) (ESAMP, 2003). It is important to note, however, that these studies did not properly assess the potential health risks of $PM_{2.5}$ in their health damage estimates. In terms of methodology, our study is based on actual cost estimates as against other studies based on various proxy measures. A comparative assessment of $PM_{2.5}$ related damage estimates cannot be performed due to absence of similar studies carried out in the context of South Asia. In fact, our study is one of the few which makes an attempt to quantify health effects of $PM_{2.5}$ resulting from auto-diesel emissions.

While we believe our results advance beyond earlier estimates, there are some limitations worth mentioning. Firstly, the COI estimates only provide lower bound values as against willingness-to-pay (WTP) estimates. Secondly, as noted by Freeman (2000), CR function transfers might give very misleading results due to five main reasons: a) differences in pollution levels between the source country and the developing country under study, b) differences in the age structure, c) differences in the physical and chemical compositions of particulate matter, d) differences between the pollution measures used in the analysis and the actual exposures of the population at risk, and e) differences in social, economic and cultural factors. None of the existing studies on CR function transfers shed any light on the relative importance of these five factors.

Freeman (2000) also state that "the evidence on the prevalence and importance of these factors is mixed and the bottom line is that the CR function transfer will often be necessary in the estimation of health benefits from controlling air pollution". In view of these considerations, we believe our estimates would be of direct relevance in assessing the costs and benefits of different pollution control interventions.

5. INTERVENTIONS FOR POLLUTION CONTROL: COSTS AND BENEFITS

This section of the analysis deals with the costs and benefits of various pollution control interventions. The selection of pollution control options is based on action programs identified by the Air Resources Management Centre (ARMC) of the Ministry of Natural Resources and Environment in its Clean Air Action 2005 and cover the following interventions.

- Reducing the price differential between diesel and petrol.
- Introducing road user charges.
- Introducing an effective vehicle inspection and maintenance program (I/M).
- Improving the quality of diesel.

The assessment in this section is based on the benefit estimates prepared in Section 4 above and the cost estimates prepared by other studies. In other words, each pollution control option below is assessed considering avoidable future health damages based on current damage costs. More details on assumptions and methodological procedures relating to each control intervention are discussed separately below.

5.1 Reducing the price differential between diesel and petrol[12]

At the outset, some background information and clarifications on the proposed pricing policy option is in order. As stated earlier, Sri Lanka has been maintaining a significant price differential between petrol and diesel over the past several decades. As at June 2005, petrol and diesel were priced at Rs.80/litre and Rs.50/litre respectively indicating a 60 per cent price differential between the two products. In terms of the cost of production, a litre of petrol is 15 per cent higher than that of diesel. However, the existing tax structure continues to maintain a significant price differential between petrol and diesel primarily due to political factors. In fact, the existing fuel price policy does not take into account potential externalities associated with the high consumption of auto-diesel.

[12] The Ministry of Environment in its Clean Air Action 2005 program defined this policy option as a change in price ratio 4:5.

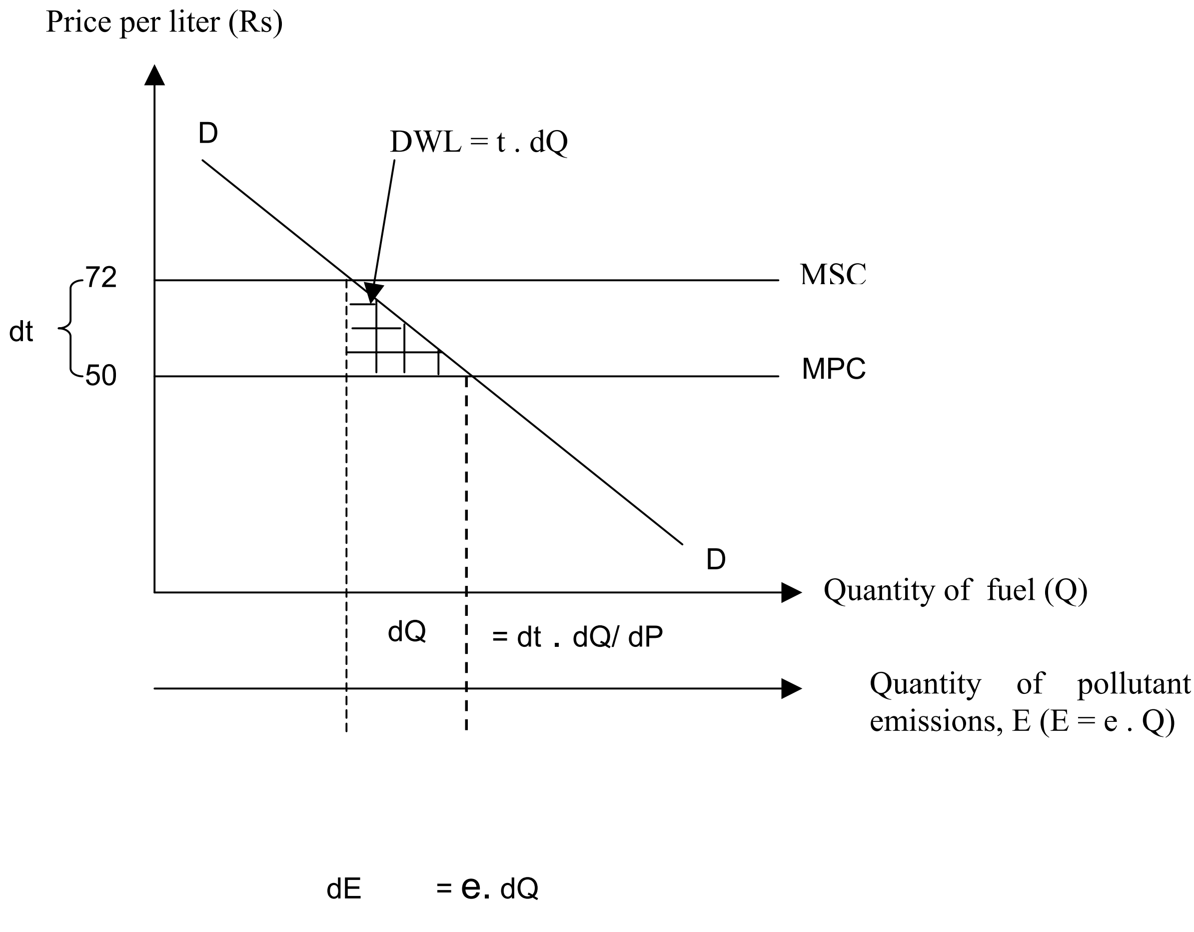


Figure 9. Pollution reductions with fuel price increases: marginal social costs

Notes: DWL= dead weight loss; MSC = marginal social costs; MPC= marginal private costs

The costs and benefits of reducing the price differential between petrol and diesel can be assessed in terms of the marginal social costs (MSC) of auto-diesel emissions. From the analysis given in Section 4, it is clear that the total health damage due to PM is in the region of Rs. 18 billion per annum in the middle case scenario. The evidence also indicates that the share of the auto-diesel sector is about 89 per cent of the total health damage (see Table 3) or Rs. 16 billion per annum. Based on auto-diesel consumption in Colombo in 2004, the health damage of auto-diesel works out to be Rs. 22.00 per litre.[13] The possibility of reducing the price differential between petrol and diesel and its likely impact on emission levels is illustrated in Figure 9. The analysis given in Figure 9 is an attempt to assess the impact of a tax on auto-diesel equal to the difference between marginal social costs (MSC) and marginal private costs (MPC). The gap between MPC and MSC is the externality cost associated with auto-diesel consumption, which affects the general public. It is assumed that the tax induces consumers to reduce diesel consumption by manipulating the price that they have to bear and the resulting dead weight loss (DWL) is equal to the shaded area,

[13] Based on the assumption that 1 Mt (diesel) = 1,196 litres of diesel.

approximated by the rectangle, $DWL = t \cdot dQ = t \cdot dt \cdot dQ/dP$ where dQ/dP is the slope of the demand curve.

The lower part of Figure 9 represents an alternative x–axis, showing how emissions represent a constant times fuel consumption, as long as the demand changes do not change emission factors. Thus, the effect on emissions of a change in the fuel tax rate is the emission factor times the demand change: $\partial e = e \cdot \partial Q = e \cdot \partial t \cdot \partial Q/\partial P$ where e is the quantity of pollutant emissions (Eskeland and Xie (1998) and Eskeland and Devarajan (1996).

We measure the slope of the demand curve ($\partial Q/\partial P$) based on existing empirical work on Sri Lanka. For example, work by Chandrasiri (2006, 1999), Jayaweera (1999) and ESAMP (2003) deal with own-price and cross-price elasticities of road-fuel in Sri Lanka. These studies also provide both short-run and long-run elasticity values. The estimates are based on standard econometric procedures and therefore, findings could be used to assess the costs and benefits of upward price adjustments of auto-diesel. Accordingly, the own-price elasticity coefficient for auto-diesel by Chandrasiri (2006) is -0.081 and -0.669 for short-run and long-run respectively while the cross-price elasticity for petrol is +0.081. The estimates prepared by Jayaweera (1999) stand at -0.154 and -0.339 for short-run and long-run respectively. Considering the time coverage and econometric procedures of the two studies, the elasticity coefficients given by the former study are used here in assessing the potential costs and benefits of reducing the price differential between diesel and petrol.

Table 12. Benefits and costs of increasing diesel prices by 44 per cent (NPV at 7.25 %, 2006 – 2020)

Cost/ Benefit Items	**Unit**	**Total**
PM reduction due to 44 % increase in diesel price - ST	tons	- 1585
PM reduction due to 44 % increase in diesel price - LT	tons	- 37173
PM increase in petrol due to 44 % increase in diesel price - LT	tons	+ 864
Net effect of PM reduction due to 44 % increase in diesel price	tons	- 37895
Health benefits @ Rs. 2.58 Mn/ton	Rs. Bn	10.3
Social cost @ Rs.22/litre	Rs. Bn	4.5
Net benefit @ 7.5%	Rs. Bn	5.9

Source: Appendix 4

Notes:

1) Assumed current price of diesel = Rs. 50/litre.

2) Rs. Bn. = Rupees in billions

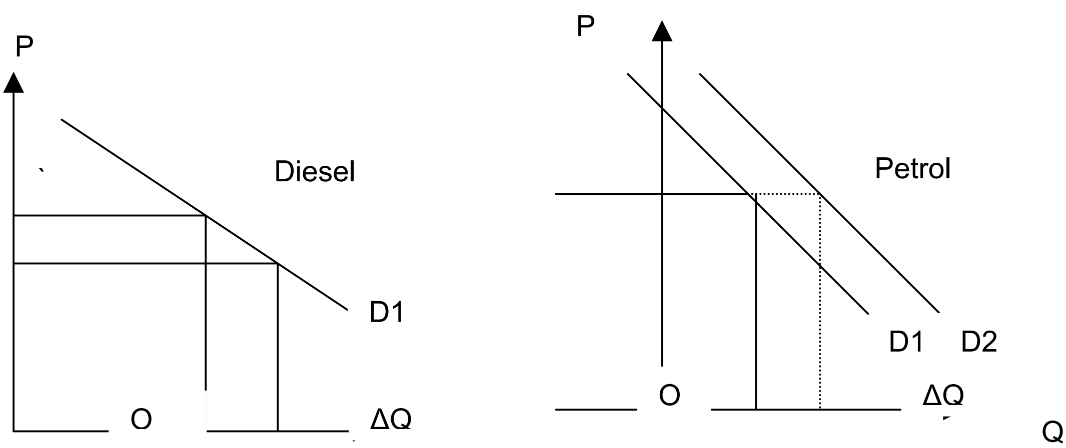
3) ST = Short-term; LT = Long-term

Based on the methodological outline given above, we defined the current market price of Rs. 50/litre fixed by the government as the MPC of diesel and ∂t of Rs. 22/litre as the externality cost of diesel. Thus, an application of externality cost to the existing price structure involved a 44 per cent increase in auto-diesel price (i.e., Rs.72/litre) and a reduction of the price differential between petrol and diesel of 11% or Rs.8/litre.[14] In terms of elasticity estimates, this implies a 2.9 per cent and 24.1 per cent decrease in the demand for auto-diesel per annum in the short-run (2006-2010) and long-run (2011-2020) terms respectively. It also implies an increase in the demand for petrol by 2.9 per cent in the long-run due to the substitution effect. In terms of stock of pollution, it implies a reduction of PM_{10} emissions by 1,585 tons and 37,173 tons in the short and long-run respectively.[15] An increase in the stock of PM from petrol vehicles (i.e., 864 tons in the long run – Table 12) due to an increase in petrol consumption is also expected. The definitions of short and long-run periods in assessing the impact of diesel price increases are based on the assumption that substitution from diesel to petrol vehicles takes place after five years of upward price adjustment.

Figure 10 is an attempt to analyze the potential social costs and distributional effects of reducing the price differential between petrol and diesel. Based on the above computations, ΔP (change in price) of Rs.22/litre (or a 44% increase) results in ΔQ of 420 and 9790 Mts of diesel per annum in the short-run and long-run respectively. It also involves a transfer payment from vehicle owners to the government. Thus, the social costs (SC) or deadweight loss (DWL) of a diesel price increase must be taken into account in analyzing the costs and benefits of reducing the price differential between diesel and petrol. The estimated SC are about Rs. 4.5 billion and the resulting net benefit over a period of 15 years (2006-2020) is about Rs. 5.9 billion discounted at 7.25 per cent. (The discount ratio of 7.25 is based on Treasury bill rates and assumed to be more relevant than commercial rates for the present analysis.)

Figure 10 – Impact of Reducing Price Differential between Petrol and Diesel

ΔP



The distributional impact is yet another important issue that needs to be taken into account in assessing upward price adjustments of auto-diesel. As stated earlier, a reduction in the price differential between diesel and petrol based on externality costs of auto-diesel results in an upward price increase of Rs. 22/litre. An analysis of auto-

14 Based on the retail price of Rs. 72/litre and Rs. 80/litre of diesel and petrol respectively.
15 This is based on the assumption of PM_{10} 12kg/ton fuel. See ESMAP 2003.

diesel consumption by type of vehicle reveals that buses and lorries account for about 61 per cent of diesel consumption while diesel cars and dual-purpose vehicles account for about 3.1 and 31.8 per cent of diesel consumption respectively. In terms of tax burden, the owners of buses and lorries are in a position to pass it on to their customers while in the case of diesel-powered cars and D/Ps, it has to be borne by vehicle owners.

In Sri Lanka, this has been a major concern of successive governments over the past 15 years. A slightest increase in auto-diesel prices leads to immediate increases in bus fares and costs of vegetables, rice, etc. (Indraratna, 1994). From a political economy point of view, these are rather unpopular policy options and hence, receive little or no support from the government. The generally accepted philosophy is that the taxes on goods that have externality costs should be adjusted upwards to reduce their consumption to a social optimum, and any additional revenue collected should be used to adjust general tax rates downwards (World Bank, 2004) Accordingly, if the additional tax income could be used to finance road provision and maintenance (i.e., a road development fund) rather than increasing indirect taxes (e.g., value added tax), the benefits would be shared by society at large and hence lead to a double dividend effect situation. This means proposed pollution tax could be used to reduce other (distorting) taxes in addition to reducing auto-diesel emissions.

5.2 Introducing road user charges

This section of the analysis deals with impact of road user charges (UCs) on PM reduction in diesel-powered vehicles. Although UCs include various taxes and fees levied on road use, fuels and motor vehicles, the present analysis is confined to registration fees and annual license fees. This is mainly due to the lack of empirical evidence on the impact of other types of UCs (for example, fuel taxes and import duties) on the demand for vehicles. As revealed by some of the existing evidence (TSPC, 1996), road user charges in Sri Lanka are not directly linked to road damage costs of different types of vehicles. Moreover, existing user charges do not take into account social costs such as pollution and congestion. The assessment given in Table 13 and 14 are based on vehicle projections for diesel-powered vehicles from 2006 to 2020 (ARMC, 2003c) and the assumption that increases in UCs take place once in five years starting from 2006 i.e., 2006, 2011 and 2016. The impact of UCs on the demand for diesel-powered cars, D/Ps, buses and lorries is based on existing empirical work and the coefficient values employed in the analysis are -0.035, -0.0963, -0.192 and -0.28 respectively (Chandrasiri, 1996 & 2006; ESAMP, 2003). Of these elasticity estimates, the high value for lorries may be due to its high user charges relative to the other vehicle categories, for example, it is 2.5 times higher than that of diesel cars. In addition, certain data limitations associated with user cost elasticity estimates are also worth noting. For example, the existing data base systems maintained by the regulatory authorities are not comprehensive enough to segregate the total vehicle population in terms of different user charges particularly on a time series basis. The estimates are therefore based on broad groupings of different types of vehicles.

The evidence (Table 14) reveals that a 10 per cent increase in UCs for diesel-powered vehicles is expected to reduce the demand for vehicles and thereby reduce PM_{10} emissions by 1,332 tons over a period of 15 years (2006-2020). In terms of health benefits, this amounts to Rs. 401 million at a social cost of about Rs. 8 million.

The estimated net benefit is about Rs. 393 million discounted at 7.25 per cent. Similarly, a 20 per cent increase in UCs would lead to PM reductions of 2,674 tons and net benefits of Rs. 805 million. From this evidence, it is clear that highest pollution reductions can be achieved by increasing UCs for diesel-powered D/Ps and buses as they account for 86 per cent of expected pollution reductions. It also shows the possibility of increasing UCs on a discriminatory basis in order to achieve targeted pollution reductions. This means increasing UCs could be used as an effective strategy to reduce particulate matter as well as heavy dieselization of D/Ps. Similarly, high UCs for lorries would minimize road damage costs in addition to gains in pollution reduction.

Table 13. Impact of 10% and 20% increase in annual user charges (registration fees and annual license fees)

Vehicle type	**Impact in tons**		**Health Benefits @ Rs. 2.58 Mn/t – NPV @ 7.25%**		**Social costs Rs. Mn NPV @ 7.25%**	
	10%	**20%**	**10%**	**20%**	**10%**	**20%**
Car	38	76	11	23	0.67	1.59
D/P	539	1057	187	323	5.31	11.45
Bus	609	1240	167	385	0.68	1.87
Lorry	146	301	36	93	1.20	3.67
Total	**1332**	**2674**	**401**	**824**	**7.86**	**18.58**

Source: Appendix 5

Table 14. Benefits and costs of increasing user charges (registration fees and annual license fees) (NPV @ 7.25 % in Rs. Millions, 2006 – 2020)

Item	**Unit**	**@ 10% increase in UCs**	**@ 20% increase in UCs**
PM reduction	tons	1332	2674
Health benefits @ Rs. 2.58 Mns/t	Rs. Mns	401	824
Social costs	Rs. Mns	7.86	18.59
Net benefit @ 7.25%	Rs. Mns	392.81	805.08

Source: Appendix 5

Note: Rs. Mn = Rupees in millions

Similar to the line of arguments developed in the case of a price differential between diesel and petrol, the distributional impact of UCs can be considered as another interesting case study for potential double dividend effects. In fact, majority of D/P owners belong to the high income segment of the population and vehicle usage is mainly for private purposes. Hence, the question of transferring the additional cost burden over to low income earners does not arise. In the case of buses and lorries, additional UCs can easily be passed on to various user groups. As argued earlier, if the incremental revenue from UCs could be used to finance a Road Development Fund (rather than having the fund financed through an increase of the general tax rates), it may lead to a double dividend effect situation.

5.3 Introducing an effective vehicle inspection and maintenance (I/M) program

Inspection and maintenance (I/M) refers to a vehicle emission control system where both emission inspection and vehicle maintenance programs are initiated and implemented by the government. Although difficult to implement, an effective I/M program can reduce vehicular emissions significantly. Based on the findings and recommendations of the ARMC (2003b) study, we analyzed the potential costs and benefits of an I/M program for Colombo based on the cost estimates and vehicle throughput given in Table 15.[16] We worked on the assumption that the costs of supervision and enforcement would be met by the government. The costs of building and operating the vehicle inspection centres would be met by private investors as well as vehicle owners under the "polluter pays" principle. With respect to repair costs, we assumed that only about 10 per cent of the vehicles that failed the emission test would require major repairs as the majority can easily be brought into compliance with a simple and cheap adjustment of the air-fuel ratio (ARMC, 2003b).

The assessment of I/M program based on the above cost details and assumptions are given in Table 16. It covers diesel-powered cars, dual-purpose vehicles, buses and lorries. The bulk of pollution reductions are expected from the latter three groups of vehicles. In fact, D/Ps and buses account for about 87 per cent of PM reductions from the proposed I/M program. As noted earlier, these three groups of vehicles account for about 25 per cent of the total vehicle population, but accounts for about 84 per cent of PM emissions. The assessment also revealed that the costs and benefits of the I/M program targeted at diesel-powered vehicles are in the region of Rs. 228 Mn and Rs. 1,438 Mn respectively discounted at 7.25 per cent (Table 17). These benefit estimates, however, do not reflect the potential benefits of the I/M program due to improved fuel economy during the post-inspection period resulting from minor repairs and adjustments to the air-fuel ratio. We expect strict enforcement of I/M requirements through principal mechanisms; window stickers and the vehicle taxation process. The window sticker should be affixed to each vehicle as it passes inspection.

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[16] All cost estimates are from ARMAC (2003b) and adjusted for inflation.

Table 15. Inspection and maintenance – cost and vehicle throughput per inspection lane

Cost Item	Unit	Value
1. Capital investments- L/D	Rs. Mn	22.38
2. Capital investments- H/D	Rs. Mn	37.7
3. Inspection facility cost – L/D	Rs./per year	700
4. Inspection facility cost – H/D	Rs/ per year	1155
5. Supervision and enforcement fees (emission compliance sticker) - L/Ds	Rs./per year	350
6. Supervision and enforcement fees (emission compliance sticker) - H/Ds	Rs/ per year	580
7. Repair cost	Rs. per vehicle	13867
Vehicle throughput		
1. Inspection time	Minutes/vehicle	10
2. Hours of inspection	a day	14
3. Days of inspection	Year	300
4. Total inspection capacity	Year/ vehicle	25,200
5. Capacity factor	per cent	60
6. Actual number of vehicle inspected	Year/ vehicle	15,120
7. Expected vehicle failure rate L/D	per cent	40
8. Expected vehicle failure rate H/D	per cent	20

Source: ARMC (2003b)

Notes:

1) L/D = light-duty vehicles (cars and dual-purpose vehicles)
2) H/D = heavy-duty vehicles (buses and lorries)
3) Rs. Mn = Rupees in millions

Table 16. Pollution reductions of an I/M program for diesel-powered vehicles by type of vehicles, (2006 – 2016)

Diesel-powered vehicles	Tons	%	Health Benefits @ Rs. 2.58 Mn/t discounted at 7.25%	%
Cars	416	5	81.23	5
D/Ps	3101	36	604.90	36
Buses	4373	51	852.98	51
Lorry	649	8	126.58	8
Total	**8539**	**100.0**	**1665.69**	**100**

Source: Appendix 6

Notes: Mn = millions; t = tons

Table 17. Benefits and costs of an I/M program for diesel-powered vehicles (NPV @ 7.25 % in Rs. Millions, 2006 – 2016)

Item	Unit	Total
PM reduction	tons	8540
Health benefits @ Rs. 2.58 Mn/ton	Rs. Mn	1665.70
Capital and operating costs	Rs. Mn	228.13
Net benefit	Rs. Mn	1437.57

Source: Appendix 6

Note: Rs. Mn = Rupees in millions

5.4 Improving the quality of diesel

The quality enhancement program can be considered as one of the most important pollution control options in Colombo given the high sulfur content of auto-diesel and the severity of $PM_{2.5}$ emissions. In fact, this has been identified as one of the biggest challenges faced by the road-transport sector, and diesel fuel reformulation[17], in particular, has been examined by various technical committees including the ARMC's (2003c) latest study. The present analysis is based on the cost estimates given in that study with necessary adjustments for inflation.[18]

As noted by the existing body of evidence, diesel fuel reformulation requires both short range (up to 2010) and long range (2011-2015) solution options. The former refers to maximum utilization of existing hydro-treating capacity with the use of more low sulfur crude oil and reducing sulfur to a range of 2,500 to 3,000 ppm. The latter, long-range solutions, includes investments in a hydro-cracker to: a) produce more distillate and move the refinery production closer to market demand, and b) give the refinery full flexibility to meet lower sulfur and other diesel fuel specifications. It has been stated that with this investment, fuel quality standards stipulated by EURO II/III and World-Wide Fuel Charter-Diesel Category 2 will become feasible.

In line with these considerations, the following estimates were used for evaluating the costs of both short and long range solutions for reformulating diesel fuel.

a) Short range – Capital costs Rs. 2.6 Bn

- Annual operating costs Rs. 0.5 Bn
- Additional product costs Rs. 0.30 /lit

a) Long range – Capital costs Rs. 29.3 Bn

- Annual operating costs Rs. 4.9 Bn
- Additional product costs Rs. 2.38 /lit

[17] This consists of two components: a) top priority – reduce sulphur content, and b) other priorities – back-end-volatility (T95) and density.

[18] At a rate of 5% and 7.5% for estimates in US$ and Rupee values respectively.

The benefits assessment of diesel fuel reformulation is based on the following assumptions:

- Diesel fuel continues to be by far the one with the highest demand in the road transport sector.

- The estimated product demand is based on the scenario that petrol demand grows faster at the expense of diesel.

- Diesel fuel meeting the proposed short range specifications would reduce PM_{10} emissions by 10% and long range specifications would reduce PM_{10} emissions by 15% (ARMC, 2003c).

Based on the above assumptions, the estimated costs and benefits of a short-run fuel quality enhancement program (2006-2010) were Rs. 3.4 Bn and Rs. 2.8 Bn respectively discounted at 7.25 per cent (Table 18). The total costs were defined to include capital costs of Rs. 2.6 Bn, annual operating costs of Rs. 0.5 Bn per annum for five years plus additional product costs of Rs.0.30 per litre of diesel. Similarly, the estimated costs and benefits of a long-run fuel quality enhancement program (2011-2020) were in the region of Rs. 14.1 Bn and Rs. 2.1 Bn (based on 15 per cent PM reduction rate) respectively discounted at 7.25 per cent (Table 18). The total costs were defined to include capital cost of Rs. 29.3 Bn, annual operating cost of Rs. 4.9 Bn per annum plus additional product cost of Rs. 2.38 per liter of diesel (2011-2020). As claimed by petroleum industry specialists, long-run quality enhancement programs may increase PM_{10} emission reductions by 20 to 25 per cent (ARMC, 2003c). Accordingly, a 20 per cent reduction in PM_{10} emissions will lead to health benefits of Rs. 2.7 Bn discounted at 7.25 per cent. The combined impact of short and long-range fuel quality enhancement programs based on PM_{10} reductions by 15 and 20 per cent are analyzed in Table 19.

Table 18: Benefits and costs of fuel quality improvement (NPV @ 7.25 %, Rs. Billions, 2006 – 2020)

Item	**Unit**	**Step 1 @ 10% PM reductions 2006-2010**	**Step 2 2010-2020**	
			@15% PM reductions	**@ 20% PM reductions**
PM reduction	tons	3,030	9,090	12,120
Health benefits @ Rs. 2.58 Mn/tons	Rs. Bn	2.817	2.1	2.7
Capital and operating costs	Rs. Bn	3.412	14.1	14.1
Net benefit	Rs. Bn	-0.595	-12.0	-11.4

Source: Appendix 7

Note: Rs. Bn = Rupees in billions

Table 19: Combined impact of fuel quality improvement (NPV @ 7.25 %, Rs. Millions, 2006 – 2020)

Item	Unit	Step 1 & Step 2 @ 15% PM reductions	Step 1 & Step 2 @ 20% PM reductions
PM reduction	Tons	12,120	15,150
Health benefits @ Rs. 2.58 Mns/t	Rs. Bn	3.5	4.2
Capital and operating costs	Rs. Bn	17.0	17.0
Net benefits	Rs. Bn	-13.5	-12.8

Source: Table 18 and Appendix 7

Table 20. NPV of net benefits

Control Option	NPV of Benefits Discounted @ 7.25% (Rs. Mn)	Rank
1. Reduce the price differential between diesel and petrol	5,863	1
2. Increase Road User Charges – 10%	393	
3. Increase Road User Charges – 20%	805	3
4. Introduce an I/M program	1,437	2
5. Improve fuel quality – ST	-596	4
6. Improve fuel quality – LT @15%	-12,021	
7. Improve fuel quality – LT @ 20%	-11,342	
8. Improve fuel quality – ST & LT @15%	-13,511	
9. Improve fuel quality – ST & LT @ 20%	-12,831	

Notes: Rs. Mn = Rupees in millions; ST= short-run; LT = long-run; I/M = inspection and maintenance

The overall assessment of pollution control options in terms of net benefits discounted at 7.25 per cent is summarized in Table 20, and the evidence reveals the high benefit potential of policy-oriented interventions as against technical options. It also shows the upward adjustment of auto-diesel prices as the most important pollution control option followed by I/M programs and increase in road user charges. The last two options also provide the advantage of targeting pollution control measures on selected categories of vehicles namely, dual purpose vehicles and buses.

Another important issue worth considering is the use of the revenues that could be generated through an increase of diesel prices and road user charges. Based on our estimates, the potential government revenue from an increase in auto-diesel prices by Rs. 22/litre is about Rs. 11 billion for 15 years (2006-2020) discounted at 7.25 per cent. Similarly, revenue generation potential from a 10 per cent and 20 per cent increase in user charges has been estimated to be in the region of Rs. 1.2 and 1.5

billion respectively for 15 years discounted at 7.25%. The earmarking of these revenues for alternative pollution reduction strategies such as retrofitting buses and lorries would be an important policy consideration given the budgetary constraints at the national level.

Table 21. Potential government revenue from an increase in user charges

Vehicle type	**NPV @ 7.25% for 2006-2020 Rs. Mns**		**2006 - Rs. Mns**	
	Increase of UCs by 10%	**Increase of UCs by 20%**	**Increase of UCs by 10%**	**Increase of UCs by 20%**
Car	97.58	114.83	53	57
D/P	958.52	1166.04	354	384
Bus	78.90	93.77	34	36
Lorry	105.55	123.80	46	48
Total	**1240.55**	**1498.44**	**487**	**525**

Notes: D/P = Dual-purpose vehicles; Rs. Mn = Rupees in millions; UC= User charges

6. CONCLUSIONS AND RECOMMENDATIONS

The purpose of the present study has been two-fold: a) to estimate the health impacts of auto-diesel emissions in the city of Colombo, and b) to compare the costs and benefits of various policy options in controlling auto-diesel. The evidence of the first part of the analysis revealed the high growth rate in the number of diesel-powered vehicles and auto-diesel consumption over the past 25 years. Given the high sulfur content of auto-diesel, relatively old diesel-powered fleets on the roads, and heavy traffic congestion, auto-diesel appears to be the main source of particulate matter (PM) emissions in the urban environment of Colombo. The transport sector accounts for about 88 per cent of PM in the city and within the transport sector, diesel vehicles account for about 89 per cent (Table 3) of PM_{10} emissions in Colombo. An assessment of air quality monitoring statistics in Colombo revealed that the observed values of PM_{10} and $PM_{2.5}$ in Colombo are far above the permissible standards of USEPA over the past several years.

The estimated health damage due to auto-diesel emissions based on the adjusted COI approach is in the range of Rs. 22 to Rs. 17 billions per annum based on high and low impact scenarios. The analysis relating to the costs and benefits of various pollution control interventions indicate that potential health benefits exceed the costs associated with pollution control interventions. The costs of fuel quality enhancement programs, however, are higher than the expected benefits.

Considering the deteriorating air quality levels in Colombo and potential health damage associated with particulate matter, we propose the following policy recommendations for controlling auto-diesel emissions:

1. Of the various pollution control options, inspection and maintenance programs and a 20 per cent increase in user charges should be considered as priority items for implementation. The policy option of reducing the price differential between petrol and diesel is not recommended in view of the heavy tax burden that would have to be borne by low-income earners.

2. Emissions of smoke and soot from diesel vehicles are believed to be the main sources of particulate matter. Therefore, vehicle inspection and maintenance programs should be given top priority in an attempt to control vehicular emissions in Colombo. However, implementation is difficult and requires both policy and technical measures. The former refers to regulatory measures for the effective enforcement of I/M programs. More specifically, this involves establishing on-the-road emission standards and the introduction of emission test certificates as a requirement for the annual registration of vehicles. The technical measures include the construction of inspection lanes for light-duty (L/D) and heavy-duty (H/D) vehicles, the establishment of a central vehicle inspection database, appointing private sector organizations to carry out I/M activities, and the establishment of a separate regulatory unit in the government or semi-government sector for the regular supervision of I/M programs. The capital and operating costs of an I/M program should be recovered through a fee paid by the vehicle owner to the inspection station. We estimate necessary inspection charges to be around Rs. 700 and Rs. 1155 for L/D and H/D vehicles respectively. We also recommend emission compliance stickers to be priced at Rs. 350 and Rs. 700 for L/D and H/D vehicles respectively to recover government supervision and enforcement costs.

3. The government should consider user charges as an important policy option in controlling auto-diesel emissions. As pointed out in several studies, this is an area which requires immediate attention by the government as existing user charges do not reflect the true economic costs of road usage by different categories of vehicles. We recommend an increase in registration and annual license fees for diesel-powered vehicles, particularly D/Ps and lorries, to be raised by 20 per cent. Following the recommendations in several studies, we also recommend a detailed study on road user charges with a special emphasis on road damage costs.

4. Considering the high sulfur content of auto-diesel and the potential health damage of auto-diesel emissions, short-term fuel quality enhancement programs are also recommended for the immediate attention of policy-making bodies. The additional costs involved in this regard could be recovered through an additional levy of Rs. 1.24 per litre of diesel.

5. Considering the potential health damage associated with the heavy consumption of low quality auto-diesel, both technical and policy options should be implemented on a complementary basis in order to realize the full benefits of pollution control interventions.

REFERENCES

ADB (Asian Development Bank). 1996. Economic evaluation of environmental impacts: workbook. Manila, The Philippines.

Akeson, L.; K. Davidson; L. Deck; B. Firlie; E. King; D. McCubbin; and E. Post. 2000. Final heavy duty engine/diesel fuel rule: air quality estimation, selected health and welfare benefits methods, and benefit analysis results. US Environmental Protection Agency.

Alberini, A. 1997. Valuing health effects of air pollution in developing countries: the case of Taiwan. Journal of Environmental Economics and Management. 34 (2). 107-126.

Alberini, A. and A. Krupnick. 2000. Cost-of-illness and willingness-to-pay estimates of the benefits of improved air quality: evidence from Taiwan. Land Economics. 76 (1). 37-53.

ARMC (Air Resource Management Centre), 2003a. Fiscal Policies on Fuels and Vehicles in Sri Lanka. Ministry of Environment and Natural Resources, Sri Lanka.

______ 2003b. Vehicle emission reduction in Sri Lanka. Ministry of Environment and Natural Resources, Sri Lanka.

______ 2003c. Motor fuel quality improvements in Sri Lanka. Ministry of Environment and Natural Resources, Sri Lanka.

Bofetta, P.; M. Dosemeci; G. Gridley; H. Bath; T. Moradi; and D. Silverman. 2001. Occupational exposure to diesel engine emissions and risk of cancer in Swedish men and women. Cancer Causes Control. 12. 365-374.

CEA (Central Environment Authority). 1999. Baseline study for air pollution in Sri Lanka.

Chandrasiri, S. 1999. Controlling automotive air pollution: the case of Colombo City. EEPSEA Research Report Series. http://www.idrc.org.sg/eepsea

Chandrasiri, S. 2006. Demand for road-fuel in a small developing economy: the case of Sri Lanka. Energy Policy. 34/14. 1833-1840.

Cohen, A.; R. Anderson; B. Ostro; K.D. Pandy; M. Krzyzanowski; N. Kunzl; K. Gutschmidt; A. Pope; I. Romieu; J. Samet; and K. Smith. 2003. Mortality effects of particulate air pollution in the urban environment. M. Ezzati; A.D. Lopez; A.D. Rogers; and C.J.L. Murray (ed.), *In* Comparative quantification of health risks: global and regional burden of disease due to selected major risk factors. WHO. Geneva, Switzerland.

De Silva, A.; K.C.S. Dalpadathu; S.M. Samarasinghe; and A.M. Dias. 1997. Assessment of the prospects of paying wards in government hospitals as complementary financing for hospitals. Ministry of Health. Colombo, Sri Lanka.

Dockery D.W.; J. Cunningham; A.I. Damokosh; L.M. Neas; J.D. Spengler; P. Koutrakis; J.H. Ware; M. Raizenne; and F.E. Speizer. 1996. Health effects of acid aerosols on North American children – respiratory symptoms. Environmental Health Perspectives. Vol. 104 (5): 500-505.

ESAMP. 2003. Sustainable transport options for Sri Lanka. 1. The World Bank. Washington D.C., USA.

Eskeland, G.S. and J. Xie. 1998. Acting globally while thinking locally: synergy in air quality programmes for transport in Mexico and Santiago. Working paper. The World Bank. Washington D.C., USA.

Eskeland, G.S. and S. Devarajan. 1996. Taxing bads by taxing goods: pollution control with presumptive charges. Directions in development. Working paper, The World Bank. Washington D.C., USA.

Faiz, A.; C.S. Weaver; and M.P. Walsh. 1996. Air pollution from motor vehicles. The World Bank. Washington, D.C., USA.

Fraser Thomas. 2002. Community integrated solid waste management plans. Project Document, Galle Municipal Council. Sri Lanka.

Freeman III, A.M. 1994. The measurement of environmental and resource values: theory and methods, resources for the future. Washington D.C., USA.

Freeman III, A.M. 2000. The valuation of environmental health damages in developing countries: some observations. Prepared for the Biannual Workshop of the EEPSEA, 21 November 2000, Chiang Mai, Thailand. http://203.116.43.77/publications/specialp2/rick.htm

Indraratna, A.D.V. de S. 1994. Economic and environmental implications of petrol/diesel pricing. University of Colombo. Sri Lanka.

Jayaweera, D. 1999. effective steps towards traffic calming in developing countries: a case study for the metropolitan region of Colombo in Sri Lanka. PhD thesis. MIT. Boston, USA.

Krewski, D.; R. Burnett; M. Goldberg; K. Hoover; J. Siemiatycki; M. Jerrett; M. Abrahamovicz; and M. White. 2000. Reanalysis of the Harvard six cities study and the American Cancer Society of particulate air pollution and mortality. Health Effects Institute. Cambridge, USA.

Kumarage, A.S. 2000. Estimation of operational vehicle fleet 2000 update; division of traffic engineering. Department of Civil Engineering, University of Moratuwa. Moratuwa, Sri Lanka.

Lvovsky, K.; G. Hughes; D. Maddison; B. Ostro; and D. Pearce. 2000. Environmental costs of fossil fuels: a rapid assessment method with application to six cities. Environment Department Papers. Paper No. 78. The World Bank. Washington D.C., USA.

Mathes, J.A.P.; A.W.J. Kumarasinghe; and H.D. Gunawardene. 1993. Air pollution caused by vehicle emissions. Unpublished Paper, Ceylon Institute of Scientific and Industrial Research, Sri Lanka.

MEIP (Metropolitan Environnemental Improprement Programme). 1992. Clean air action plan for air quality management in the Colombo metropolitan area. Ministry of Policy Planning and Implementation. Sri Lanka.

Ministry of Health. 2000. Annual Health Bulletin.

______ 2001. Annual Health Bulletin.

______ 2002. Annual Health Bulletin.

NBRO (National Building Research Organization). 2003. Report on changing atmospheric lead levels in Colombo with discontinuation of leaded petrol in Sri Lanka. February 2003.

Pandiya, R.; G. Solomon; A. Kinner; and J. Balmes. 2002. Diesel exhaust and asthma: hypotheses and molecular mechanisms of action. Environmental Health Perspectives. 110 (Suppl 1). 103-112.

Samet, J.M.; L. Zeger; S. Dominici; F. Curriero; F. Coursac; D.W. Dockery; J. Schwartz; and A. Zanobetti. 2000. The national morbidity, mortality, and air pollution study. Health Effects Institute. Cambridge, USA.

Schwartz, J.; D.W. Dockery; L.M. Neas; D. Wypij; J.H. Ware; J.D. Spengler; P. Houtrakis; P. Speizer; and B.G. Ferris. 1994. Acute effects of summer air pollution on respiratory symptom reporting in children. Am J Respir Care Med. 150 (5). 1234-1242.

Shahwahid H.O. and Jamal Othman. 1999. “Malaysia” in Indonesia’s fires and haze. D. Glover and T. Jessup (eds). Institute of South Asian Studies, Singapore and International Development Research Centre, Ottawa, Canada.

Shanmugam, K.R. 2000. Valuations of life and injury risks: empirical evidence from India. Environmental and Resource Economics. 16. 379-389.

Sheppard, L.; D. Levy; G. Norris; T.V. Larson; and J.Q. Koening. 1999. Effects of ambient air pollution on non-elderly asthma hospital admissions in Seattle, Washington. 1987-1994. Epidemiology. 10 (1). 23-30.

TSPC (Transport Studies and Planning Centre). 1996. Study on road user charges. Colombo, Sri Lanka.

USAID/US-AEP (United States Agency for International Development/ United States Asia Environmental Partnership). 2005. Remote sensing of vehicle emissions in Sri Lanka. A survey report prepared for the Ministry of Transport.

USEPA (US Environmental Protection Agency). 1999. The benefits and costs of the Clean Air Act, 1990-2110. Report to the US Congress.

WHO (World Health Organization). 1996. International programme on chemical safety. Environmental Health Criteria 171: Diesel Fuel and Exhaust Emissions, WHO, Geneva, Switzerland.

______ 1999. Guidelines for Air Quality. Geneva, Switzerland.

Wijayamuni, R. 2003. Health effects of lead and other ambient air problems of the city of Colombo. Paper presented at a Seminar on Changing Atmospheric Lead Levels in Colombo. February 2003. A report submitted to USAID, Colombo.

World Bank. 1997. Urban air quality management strategy in Asia. Greater Mumbai Report. World Bank Technical Report Number 38. The World Bank, Washington D.C., USA.

_______ 2004. Reducing air pollution from urban transport. The World Bank, Washington D.C., USA.

_______ 2005. For a breath of fresh air: ten years progress and challenges in urban air quality management in India, 1993-2002. World Bank Environment and Social Development Unit, South Asia Region. The World Bank, Washington D.C., USA.

Appendix 1: In-patient and out-patient statistics in the public sector hospitals in Sri Lanka

Bronchial asthma	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
In-patients	149258	149415	155793	163353	173233	178510	176112
Case fatality	694	774	796	964	854	826	727
Pneumonia							
In-patients	23986	22818	23391	22954	21975	20207	25147
Case fatality	993	1215	1475	1147	1213	1074	1274
Upper-respiratory tract infection							
In-patients	67548	65732	72780	73800	80564	80597	89176
Case fatality	80	48	66	69	79	103	40

Source: Medical Statistical Unit – Ministry of Health and Annual Health Bulletin (2000, 2001 and 2002, Ministry of Health)

Appendix 2: In-patient and out-patient statistics in public sector hospitals in Colombo District

Bronchial asthma	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
In-patients	15,048	14,428	14,010	13,424	11,724	12,793	12,574
Case fatality	98	112	79	103	53	58	61
Pneumonia							
In-patients	2,019	1,981	3,204	2,514	2,502	2,619	4,826
Case fatality	206	278	421	251	280	271	365
Upper-respiratory tract infection							
In-patients	6,762	4,733	6,260	7,601	7,274	8,417	9,094
Case fatality	2	4	1	1	1	1	1
Influenza							
Cases	7	27	40	6	12	53	16
Deaths	0	0	29	0	0	0	0

Source: Medical Statistical Unit – Ministry of Health and Annual Health Bulletin (2000, 2001 and 2002, Ministry of Health)

Appendix 3: Physical impact of PM_{10} and $PM_{2.5}$

Health end	**PM**	ΔPM	β	y_0	**Target population (000)**			**Health damage (Nos)**		
		ug/m3	**Coefficient**	**MR/ DR**	**High**	**Mod.**	**Low**	**High**	**Mod.**	**Low**
Mortality	2.5	33.83	0.013272	0.00583	337.6	272.6	260.9	712.04	574.93	550.29
Morbidity										
Asthma - In-patient	2.5	33.83	0.00227	0.009535	614.8	496.4	475.1	433.31	349.87	334.88
Asthma – Out-patient	10	28.14	0.0037	0.1	614.8	496.4	475.1	6079.00	4908.37	4698.09
Pneumonia - In-patient	10	28.14	0.00207	0.023015	35.8	28.9	27.6	46.60	37.62	36.01
LRT- Out-patient	2.5	33.83	0.0272	0.023015	67.3	54.4	52.0	932.20	752.69	720.44
Total								8203.15	6623.48	6339.71

Source: Author's own calculations

Notes:

Mod. = Moderate; MR = Non trauma mortality rate; BR = Morbidity rate for different illnesses;

PM= Particulate matter; ΔPM = Change in PM

Appendix 4: Reducing the price differential between diesel and petrol

Item	Unit	2005	Short-term (ST)		Long-term (LT)	
			2006	2010	2011	2020
Auto-diesel demand projection	tons/year 000	2,000	2,120	2,600	2,730	3,950
Petrol demand projection	tons/year 000	340	378	530	582	1060
Diesel ST effect due to 44% price increase	tons/year 000		61.5	75.4		
Diesel LT effect due to 44% price increase	tons/year 000				658	952
Cross-price LT effect due to 44.2% price increase	tons/year 000				17	31
Diesel ST pollution reduction	tons	-1,585	285	349	-	-
Diesel LT pollution reduction	tons	-37,173	-	-	3,047	4,409
Petrol LT pollution increase	tons	+864	-	-	61	112
Total pollution reduction	tons	-37,894	285	349	2,986	4,297
Health benefits @ Rs.2.58 Mn/ton	NPV	10,324	735	901	7,704	11,088
Diesel private cost @22/ lit; 1196 lit per ton - NPV	Rs. Mn	8,988	624	766	6,682	9,668
Social costs @22/ lit; 1196 lit per ton – NPV	Rs. Mn	4,461	312	383	3,315	4,797
Net benefits – NPV	Rs .Mn	5,863	423	518	4,389	6,291

Source: ARMC, 2003c, ESAMP, 2003 and author's own calculations

Notes: Rs. Mn = Rupees in Millions

Assumptions:

1) Projected fuel demand is based on the scenario that gasoline demand grows faster than diesel demand (ARMC, 2003c).
2) Relative share of road-fuel consumption in Colombo = 38.6% for diesel and 30.3% for petrol (2004)
3) PM_{10} reduction = .012 pm10/ton fuel (ESAMP, 2003).
4) Discount rate of 7.25 % is based on the Treasury bill rate.

Appendix 5: Impact of user charges @ 10% and 20%

Vehicle type	Projected vehicle population		Impact of UC increase	Pollution reduction - tons		Health benefits – NPV, Rs. Mns		Social costs – NPV, Rs. Mns	
	2006	**2020**	**Coefficient**	**10%**	**20%**	**10%**	**20%**	**10%**	**20%**
Car	17,112	15,058	-0.035	38	76	11	23	0.67	1.6
D/P	93,918	174,135	-0.0963	539	1057	188	323	5.3	11.5
Bus	21,439	29,431	-0.192	609	1240	166	385	0.68	1.9
Lorry	5,807	7,972	-0.28	146	301	36	93	1.2	3.7
Total				1,332	2,674	401	824	7.9	18.7

Source: ARMC (2003c) and author's own calculations

Notes: D/P = Dual-purpose vehicles; Rs. Mn = Rupees in millions

Assumptions:

1) Projected vehicle population (VP) is based on projected numbers of diesel engine vehicles from 2001 to 2015 by the ARMC (2003c) and adjustments by the researcher in this study.
2) An increase in UCs once in five years starting from 2006 i.e. 2006, 2011 and 2016.
3) PM reductions = .012 PM_{10}/ton fuel.

Appendix 6a: Estimated pollution reductions from I/M program

Item	Unit	2005	2006	2007	2011	2016	2020
No of inspection lanes	L/D		3		3	4	0
	H/D		1		2	2	0
Vehicle inspections							
Car	Nos			6,750	6,750	6,750	9,000
D/P	Nos			38,250	38,250	38,250	51,000
Bus	Nos			11,850	11,850	23,700	23,700
Lorry	Nos			3,150	3,150	6,300	6,300
Pollution reductions	**Pollution veh/t/yr**	**tons**					
Car	0.01006	416		27.16	27.16	27.16	36.22
D/P	0.01322	3101		202.27	202.27	202.27	269.69
Bus	0.08023	4373		190.15	190.15	380.29	380.29
Lorry	0.04479	649		28.22	28.22	56.43	56.43
Total		8539		447.8	447.8	666.15	742.63

Source: Author's own calculations

Notes: D/P = Dual-purpose vehicles; Rs. Mn = Rupees in millions

Assumptions:

1) The lifetime of an inspection lane is set in this study at five years. The light duty (L/D)) vehicle inspection lane is designed for cars and DP vehicles while the heavy-duty (H/D) lane is designed for buses and lorries.
2) Lane capacity = 15,000 vehicles/year i.e., 50 vehicles/day/ @300 working days per year.
3) Inspection time = minimum 10 minutes/vehicle. Number of working hours per working day = 12 hours.
4) Expected vehicle failure rate for diesel-powered L/Ds and H/Ds are 40 and 20 per cent respectively.

Appendix 6b: Net benefits of I/M program

Type of vehicle	Health benefits –Rs. Mn NPV	Total cost, Rs. Mn (Capital+ Operating)	Net benefit, Rs. Mn
Car	81.2		
D/P	604.9		
Bus	853.0		
Lorry	126.6		
Total	1665.7	228.13	1,437.57

Source: ARMC, 2003b and author's own calculations

Notes:

1) D/P = Dual-purpose vehicles; Rs. Mn = Rupees in millions
2) Some cells are empty because the total costs (column 3) are estimated in terms of light duty (LD) and heavy duty (HD) inspection lanes rather than by type of vehicles.

Assumptions:

a) Lane construction: Cost 1 L/D = Rs. 22.38 Mn (US$223,808); H/D = Rs. 37.7 Mn (US$376,944). The lifetime of an inspection lane is five years. L/D = light duty; H/D = heavy duty.
b) Cost estimates are based on US$ values inflated @ 5 % per annum from 2002 to 2005, multiplied by the Rs/US$ exchange rate.
c) Cost estimates are based on Rupee values inflated @ 7.5% per annum
d) Required test fees (inspection facility cost) for L/Ds and H/Ds are Rs. 700 and Rs. 1155 respectively.
e) Required program supervision and enforcement fees (emission compliance sticker) for L/Ds and H/Ds are Rs. 350 and Rs. 580 per year respectively.
f) Repair cost per vehicle is estimated at Rs. 13,867 per vehicle and only 10 per cent of the vehicles (which failed the emission test) would require major repairs. The rest can easily be brought into compliance by a simple and cheap adjustment of the air-fuel ratio (ARMC, 2003b).
g) With respect to program costs and funding, the costs of supervision and enforcement are to be met by the government. The costs of building and operating the vehicle inspection centres are to be met by the private investors. These costs are also to be paid by the vehicle owners under the "polluter pays" principle.

Appendix 7: Fuel quality

Items	2005	2006	2010	2011	2020
Auto-diesel demand ton/yr 000	2,000	2,120	2,600	2,730	3,950
Additional cost @ Rs. 0.30 per lit Rs Mn		7.6	9.39	9.80	14.17
Additional cost @ Rs. 2.38 per lit Rs Mn		6034.5	7400.85	7770.89	11243.6
Short-run (2006-2010)					
Capital cost Rs. Mn.		2627.63			
Annual operating cost Rs. Mn.		525.79	525.79		
Total cost Rs. Mn	**3412.56**	3161.03	535.12		
HB @ 10% reduction of PM_{10}	**2817.04**	1534.68	1534.68		
Net Rs Mn		-1626.34	999.56		
Net benefits (NB) -NPV @ 7.25%	**(595.53)**				
Long-run (2011-2020)					
Capital cost Rs Mn			29334.59		
Annual Operating cost Rs Mn			4929.4	4929.4	4929.4
Total cost Rs. Mn	**14060.34**		41664.84	12700.29	16173
HB @ 15% reduction of PM_{10} Rs. Mn	**2038.87**		0	2302.02	2302.02
HB @ 20% reduction of PM_{10} Rs. Mn	**2718.49**		0	3069.36	3069.36
NB @ 15% PM_{10} reduction - NPV Rs. Mn	**(12021.47)**		-41664.84	-10398.27	-13871
NB @ 20% PM_{10} reduction – NPV Rs. Mn	**(11341.88)**		-41664.84	-9630.93	-13103.6
NB of Step 1+2 PM 15% reduction -NPV Rs. Mn	**(13511.03)**	1000.85	-40665.28	-10398.27	13870.98
NB of Step 1+2 PM 20% reduction -NPV Rs. Mn	**(12831.41)**	1000.85	-40665.28	-9630.93	13103.64

Source: ARMC (2003c)

Notes: D/P = Dual-purpose vehicles; Rs. Mn = Rupees in millions; HB= Health benefits; NB = Net benefits

Assumptions:

a) Projected fuel demand prepared by ARMC (2003c) is based on the assumption that petrol demand grows faster than diesel demand.

b) Short range capital costs = Rs. 2.6 Bn; annual operating costs = Rs. 0.5 Bn; and additional product costs = Rs. 0.30 /lit.

c) Long range capital costs = Rs. Bn. 29.3; annual operating costs = Rs. Bn. 4.9; and additional product costs = Rs. 2.38 /lit.

d) Cost estimates are based on US$ values inflated @ 5 % per annum from 2002 up to 2005 and multiplied by the Rs/US$ exchange rate.

e) Cost estimates are based on Rupee values inflated @ 7.5% per annum.

f) Health benefit estimates are based on total PM_{10} estimates for 2004.

g) Diesel fuel meeting the proposed short range specifications would reduce PM emissions by 10% and long range specifications would reduce PM emissions by 15%. Long range PM reductions may also go up to 20% (ARMC, 2003c).