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ENVIRONMENTAL POLLUTION IN SRI LANKA : A REVIEW

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INTRODUCTION

Sri Lanka has undergone rapid industrialisation since the early 1980's and the per capita income has almost doubled from 1985 to 1995. With the liberalisation of the economy, energy consumption has increased and the number of motor vehicles has almost tripled in the last two decades. Hydroelectricity, provided 90% of the country's electricity needs in 1985, and this share has now been reduced to around 60% due to increased energy demands for households and new industry. Power generation from thermal power plants stands at around 40% today and there is a proposal to commission a 900 MW coal fired power plant by the year 2004. At the same time petroleum consumption too has increased considerably owing to the increase in the number of vehicles. According to data available from the Ceylon Petroleum Corporation of, the annual average growth of diesel and petrol consumption was 10% and 3.5% respectively during the period, 1991-1995. Yet it is important to realise that a fair share of domestic energy is still met by burning biomass. The population of the country meanwhile has increased from 14 million in 1976 to the present 19.34 million and is expected to peak at 24 million in 2020. In fact, Sri Lanka has one of the highest population densities in the world exceeded only by a few countries such as Singapore and Hong Kong. The gross domestic product (GDP) has also increased steadily at an average annual rate of around 5% and the result of this type of economic development is the increase in environmental pollution in Sri Lanka. In a recent assessment of the state of the environment in Asia by the Asian Development Bank, the dismal progress over the last ten years and increasing threats to human health in Asia's cities have been highlighted.[1]

"Asia's environment has become so polluted and degraded that it poses a threat not just to the quality of life of its people, but also to its economic prospects. Of the world's 15 most polluted cities, 13 are in Asia as are the most populous countries.

Despite rapid and steady growth of income, at least one in three Asians still has no access to safe drinking water and at least one in two has no access to sanitation. The costs of this neglect of environment are massive. Children who ingest lead lose precious IQ points. They and their parents also suffer from chronic respiratory

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conditions and other ailments. Unsanitary living conditions and polluted water cause a variety of other gruesome conditions".

The purpose of this review is to bring into focus the various aspects of environmental pollution relevant to Sri Lanka and to highlight the research carried out in Sri Lanka on these aspects. Some selected topics related to the chemistry of the environment have earlier been published in a monograph in 1986.[2]

Air pollution

Air pollution is a serious environmental problem in Sri Lanka's major cities such as Colombo and Kandy. Motor vehicles continue to be the most significant contributor to air pollution where the fleet sizes have almost doubled in the decade 1990-2000. Highly polluting diesel vehicles and two stroke three -wheelers along with motor bicycles have increased nearly 3 fold during this period. Increasing traffic congestion, overloaded buses and trucks contribute significantly to air pollution in big cities such as Colombo and Kandy. Table 1 gives the major air pollutants in urban areas.

Table 1: Major air pollutants

Class of pollutant	Examples
Oxides of carbon	carbon monoxide, carbon dioxide
Oxides of nitrogen	nitric oxide, nitrogen dioxide
Oxides of sulphur	sulphur dioxide, sulphur trioxide
Particulates	dust, soot
Inorganic compounds	lead
Photochemical smog	ozone, peroxyacyl nitrates
Hydrocarbons	benzo(α)pyrene, benzene

Emissions of primary air pollutants, lead to the production of smogs consisting of photochemical oxidants such as ozone and peroxyacyl nitrates as secondary pollutants.[3] These destroy sensitive tissues (in people, animals and plants) reduce lung function, and aggravate asthma. Compounds such as benzo[α]pyrene given out in petroleum combustion are known carcinogens. Oxides of nitrogen and sulphur are responsible for many respiratory illnesses and asthma. Lead reduces learning abilities in children and chronic lead poisoning may result in nervous disorders. The ultimate result of air pollution is the untimely deaths of especially older people prone to heart diseases. The fine particles emitted, specially from diesel vehicles having particulate size diameters of less than 10 μm (known as the

PM10 fraction) are extremely hazardous to human health. Poor quality diesel, old vehicles and overloading are the main reasons for such pollution from motor vehicles. Pollution degrades building materials such as rubber, iron and concrete and reduces the visual quality of scenic vistas.

Air pollution monitoring

Air quality monitoring in Colombo is done at two fixed stations located at the Colombo Fort railway station and the Meteorology Department premises at Bauddhaloka Mawatha. Here the pollutants monitored every 10 minutes are sulphur dioxide, nitrogen dioxide, nitric oxide, ozone, carbon monoxide and PM 10. These data reveal[4] that, in 1996, the sulphur dioxide levels exceeded the recommended WHO standards on about 25% occasions while the ozone level exceeded the recommended levels on about 75% occasions (figure 1).

(a)

(b)

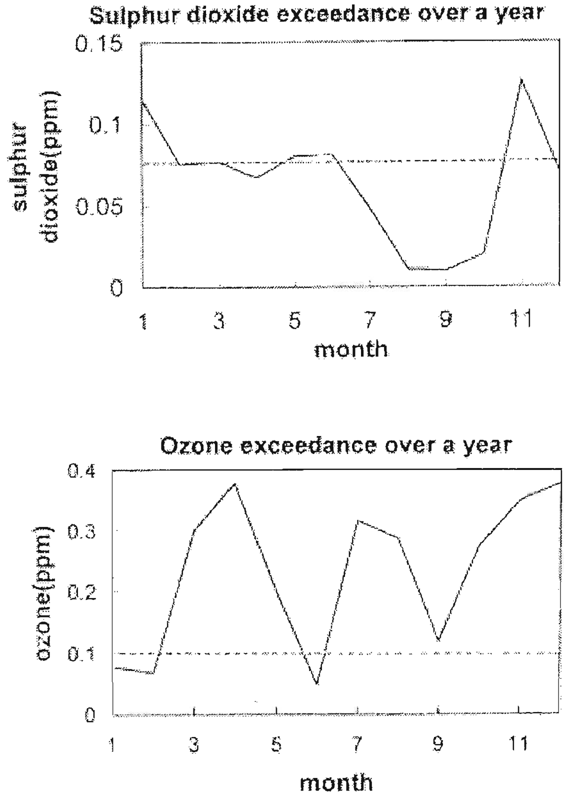

Figure 1: Excesses of monthly average concentrations of sulphur dioxide and ozone concentrations above the maximum permissible levels at the Colombo Fort Monitoring station during 1996. (Broken lines are the Sri Lankan air quality standards: SO_2, 0.08 ppm, O_3, 0.1ppm.)

Thus, on the average, in 1996, residents of Colombo city were exposed to about 1000 hours of high ozone compared to the World Health Organization guideline of 1 hour and this is significant since ozone is identified as a pollutant exacerbating asthma.[5] The results from the fixed monitoring stations also showed that the CO and NO_2 levels did not exceed the Sri Lankan ambient air quality standards of these pollutants gazetted in 1994 (table 2).

There have been other attempts earlier to monitor ambient lead concentrations, as well as blood lead levels in people exposed to lead. In a NARESA supported study[6] pollutants such as SO_2,CO, total suspended solids, fine particulates and aromatic components in ambient air have been determined.

Table 2: Ambient air quality standards for Sri Lanka (Gazette Extraordinary No. 850/4 of December 1994).

Pollutant	Averaging time(h)	Unit	Standard
SO_2	1		200(0.08)
	8	$\mu g/m^3$(ppm)	120(0.05)
	24		80(0.03)
NO_2	1	$\mu g/m^3$(ppm)	250(0.13)
	8		150(0.08)
	24		100(0.05)
O_3	1	$\mu g/m^3$(ppm)	200(0.01)
CO	1	$\mu g/m^3$(ppm)	30(26.1)
	8		10(8.7)
Lead	Anytime	$\mu g/m^3$	58(50)
	24		2.0
	Annual		0.5
Suspended	1	$\mu g/m^3$	500
Particulate	3		450
Matter	8		350
	24		300
	Annual		100

The problem of fine particulates is quite acute in Sri Lanka. In an independent study[4] the sulphation rate and dust fall have been determined at busy intersections in Colombo city. The results show that Slave Island junction is the worst affected with 0.45 mg SO_2/100cm^2/day while dust fall exceeded 0.30 mg/100cm^2/day at most locations. Dust fall values were high owing to poor maintenance of roads, construction activities and general lack of understanding amongst the public about the harmful effects of fine particles.

The average of total suspended solids was 405 $\mu g/m^3$ for a 8h period in the NARESA study and showed exceedance of Sri Lanka standards (350$\mu g/m^3$) at all sites studied with the highest recorded at Maradana (488.8 $\mu g/m^3$). In another study[7] the concentrations of the fine particulate fractions PM10 and PM 2.5 for ambient air in Colombo have been reported. These refer to particles having aerodynamic diameters of less than 10 microns and 2.5 microns respectively. The results show that the annual average values of PM10 and PM2.5 fractions were 75.12 $\mu g/m^3$ and 26.32 $\mu g/m^3$ respectively. This study carried out in 1996 records an alarming trend where fine particle concentrations exceeded the United States Environmental Protection Agency's standards (USEPA) of 50$\mu g/m^3$ for PM 10 and 15$\mu g/m^3$ for PM 2.5 fractions 95% of the time. This shows that there is a grave risk associated with the fine particles in ambient air in Colombo. Analytical results of the PM10 fraction from the Colombo Fort fixed monitoring station too showed a similar trend with the values exceeding the USEPA standard about 95% of the time (figure 2) for the period March 1998 to October 1999.

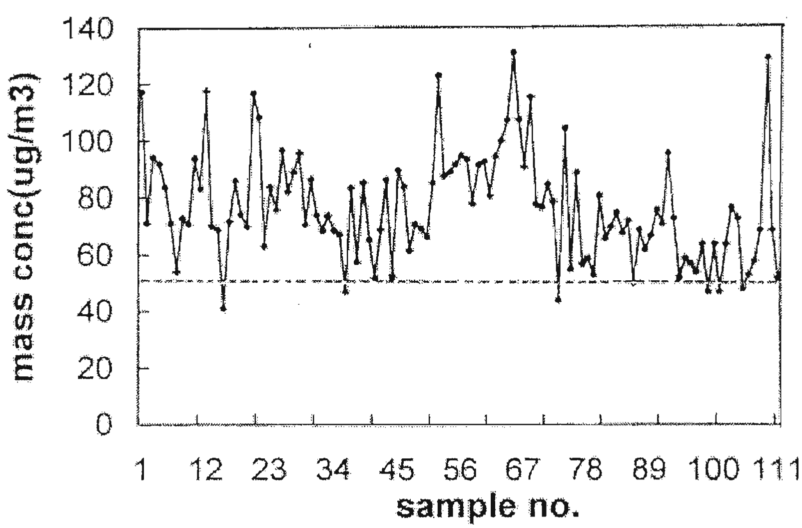

Figure 2: Variation of the PM-10 fraction in the ambient air of Colombo from March 1998-October 1999. (Broken line indicates the United States Environmental Protection Agency's standard of 50 $\mu g/m^3$ for PM-10).

The total polyaromatic hydrocarbons in ambient air averaged over several locations in the Colombo city[6] were around 730ng/m^3 with concentrations of carcinogenic polyaromatics such as benzo (α)pyrene (20 ng/m^3) benzoanthracene (14.6 ng/m^3), benzofluoroanthene (14.6 ng/m^3) and dibenzoanthracene (126.6 ng/m^3).

Ambient lead concentrations have been determined by Ponnambalam et al.[8] to be in the range 0.2-3.0 μg/m^3 for an 8 h period while the NARESA study[6] recorded an average of 0.435 μg/m^3 for an 8 h period. Both these studies were carried out at busy intersections of Colombo city where traffic volumes were high. This apparent decrease in lead concentration may be due to the reduction of lead in petrol from 0.40 g/l to 0.23 g/l between the two investigations. Although the Sri Lankan standard for the ambient lead level at 2 μg/m^3 is not exceeded, the Colombo Fort and Slave Island areas had high lead concentrations in ambient air with values of 0.626 μg/m^3 and 0.587 μg/m^3. These values correspond to daily lead exposures of 2.25 μg and 2.11μg by inhabitants of these areas and this again is a serious health problem.[6] This calculation is based on the fact that an average adult inhales approximately 2.5 litres of air per minute (3.6m^3 a day). The above lead determinations have usually been carried out from the particles trapped by a 0.45 μm cellulose filter and may not represent the total lead in the atmosphere since those lead particles in the gas phase will pass through such a filter. In a study[9] aimed at determining the total lead in the atmosphere, air was passed through a series of impingers containing dithizone and a colorimetric method was employed to determine lead. This study reports exceptionally high lead concentrations of 200 μg/m^3 and 400 μg/m^3 respectively for residential areas and close to a main highway in Colombo. These concentrations refer to lead collected over about a 3 h period and it is a matter of major concern to public health. Elemental analysis of the PM10 particulates have been carried out[10] using X-ray fluorescence techniques and the lead levels of ambient air calculated on this basis was 0.09μg/m^3 collected over a 24 h period. In a related study[11], multielement analysis of airborne dust revealed that the maximum concentrations of Al, Zn and Pb in air were, 25.6 μg/m^3, 251.0 μg/m^3, and 10.5 μg/m^3 respectively.

There is hardly any information reported on the air quality of cities other than Colombo. The air quality in Kandy which is located in a valley is of special concern since local concentration of pollutants in calm weather poses a serious health hazard. In a preliminary study using passive gas samplers, it was found that the sulphur dioxide and nitrogen dioxide levels in the Kandy city over a 24 h period regularly exceeded Sri Lanka national standards(unpublished data). Regular monitoring of pollutants in cities such as Kandy is an urgent necessity.

Indoor pollution

Indoor air pollution is an equally important aspect of air pollution which has received practically no attention in Sri Lanka. The air in enclosed spaces such as offices, classrooms and even homes can be significantly more polluted than outdoor air. In congested traffic, harmful pollutants such as benzene, carbon monoxide and airborne lead are much higher inside a closed environment of a motor vehicle than in the air outside. Some common pollutants inside buildings include cigarette smoke, radon, carbon monoxide, nitrogen dioxide, formaldehyde (from carpets, fabrics and furniture), household pesticides, cleaning solvents, ozone(from photocopiers) and asbestos. Indoor air pollution where firewood is used for cooking is a matter of serious concern. More than 80% of Sri Lankan households still use firewood for cooking and at least 70 compounds have been identified in the wood smoke and their concentrations determined.[12] Some of these compounds are carcinogenic and some cause respiratory illnesses such as acute bronchitis (table 3).

Table 3: Some toxic compounds in wood smoke

Compound	Concentration/kg of wood
Carbon monoxide	80-370 g
Benzene	0.6-4.0 g
Acetic acid	1.8-2.4 g
Lead	0.1-3.0 mg
Anthracene	20-50 μg
Phenanthrene	20-3400 μg
Benzo(α)anthracene*	400-2000μg
Dibenzoanthracene*	20-2000 μg
Benzofluoroanthracene*	400-2000 μg
Benzo(α)pyrene*	300-5000 μg

* carcinogenic

Fine particles also present in very high concentrations could lead to respiratory illnesses such as cough and bronchitis and also cancer. Data available from a study[13] in India reveal that the average Indian housewife who uses firewood for cooking is exposed to 850-4400 μg/m^3 of inhalable fine particles. Indoor air pollution from firewood use account for 6-10% of ill health in India with around 500,000 annual deaths of children under five years of age and adult women due to this type of air pollution. The incidence of lung cancer of rural woman can be attributed to wood smoke although no reliable epidemiological data are available. Indoor cooking using wood in congested areas should best be avoided and masses should be educated to use well ventilated kitchens if firewood is used as fuel. Pollution due to chalk dust in classrooms is a health hazard for both teachers and students. It has been reported[14] that the chalk dust concentration rises to around 220 μg/m^3 within

1 h leading to inhalation of approximately 3.6×10^{-3} g of chalk dust in a 1 hour lecture where the average particle size was found to be 4 μm.

Asbestos

Asbestos is a group of minerals comprised of the silicate minerals amphiboles and serpentines and have been indicated as causing bronchial carcinoma and mesothelioma of the pleura among factory workers exposed to asbestos. There is little or no information available on positive cases of asbestos causing cancer in Sri Lanka.[15] Blue asbestos which is more lethal has been banned in most developed countries.

Radioactivity

The potential sources of high radioactivity in Sri Lanka are monazite sands[16] at Beruwela and granite used as flooring in buildings. The former has radioactive thorium in its composition which gives harmful levels of exposure due to γ-decay to specially those who build houses using such contaminated sand. The presence of trace amounts of radioactive minerals in granite is also a matter of concern. Exposure to radioactive radon from granite in poorly ventilated buildings is possible and since the decay products of radon are solids, they get deposited along the membranes of the respiratory tract. These solid elements in turn are radioactive and may cause adverse health effects in humans. In a related study[17] it was estimated that the activity of radon in poorly ventilated indoor areas was 4 Bqm^{-3} while in outdoor air it was < 0.03 Bqm^{-3}. Background radioactivity levels have been determined[10] at Hendala where the beach sands contain radioactive minerals such as monazite. The average value recorded at Hendala was 5.47 mSv h^{-1} when compared to a background level of 0.46 mSv h^{-1}.

Pesticides and other volatile organics

Volatile organic compounds in air arise from a multitude of sources. In Sri Lanka, there are isolated cases of organic solvents and other chemicals leaking into workplaces in factories affecting factory workers and sometimes surrounding communities. There is extensive contamination of workers in pesticide formulating factories where proper occupational hygiene standards are not maintained[19] and many workers are reported to manifest unsatisfactory cholinesterase levels. Pesticides sprayed over vegetable plots may result in localised areas of high pesticide content in the atmosphere. Odour pollution may also result from volatile organic compounds in addition to ammonia and hydrogen sulphide generated during the anaerobic decomposition of organic matter. One particular example is the unpleasant odour emanating from the Beira lake.

Acid rain

Rain water is considered acidic if its pH value is less than 5.6 and increased acidity is the result of acidic precursors such as sulphur dioxide and nitrogen dioxide generated due to burning of fossil fuel. In countries where coal fired power plants are extensively used, the sulphate content is much higher than the nitrate component. In a study on acid rain in Sri Lanka[20] at several locations throughout the country, the occurrence of acid rain in several locations has been reported. Acid rain is commonly found in the hill country where pollutants get deposited owing to wind and also at certain locations such as Anuradhapura and Maha-Illuppallama during the months of November and December. This is likely due to the north east monsoon carrying acid precursors from the coal power plants in India. In a related study,[21] rain and fog analysis at Horton Plains indicated that the pH of rain water varied from 5.37 to 7.47 with sulphate concentrations of 0-3.39 mg/l and nitrate concentrations ranging from 0-3.54 mg/l. The fog analysis indicated much higher acidities with pH values as low as 3.88 recorded during the dry season of April to May. Such high acidities of fog may have adverse effects on sensitive ecosystems such as the observed die back of certain sections of the montane forest at Horton Plains. In a study[22] carried out at Matara it was reported that the convectional rains where there is little or no wind had relatively higher acidity compared to monsoonal rains which are accompanied by wind.

Acid rain is responsible for the depletion of fish in lakes of Scandinavian countries and the destruction of *Pinus* trees from the alpine forests of Germany. Increased acidity leaches out excessive amounts of aluminium and this presumably affects the stomatal mechanism in leaves resulting in the loss of leaves from trees. Increased acidity of fog may also explain the frost bite affecting young potato plants and it is a common practice of the upcountry potato cultivators to wash off the morning fog with plenty of water.

Greenhouse gases

The contribution of greenhouse gases towards global warming is well known. Potential sources of greenhouse gases include paddy fields and lagoons, animal farms, forest clearing and their burning, petroleum combustion and other industrial activities. There is very little information available for the contribution of greenhouse gases from Sri Lanka since local emission factors have still been not worked out. There have been some attempts[23] at computing our contributions of greenhouse gases based on emission factors developed elsewhere. The estimated amounts of greenhouse gases from the agricultural sector and forest clearing activities is given in table 4 while the emissions of greenhouse gases from the energy sector are given in table 5.

Table 4: Estimated greenhouse gas emissions from natural and agricultural activities.

	Source emission rate kT/yr		
	CO_2	CH_4	N_2O
Forest clearing	4960	15.7	0.35
Forest soils	-	-	9.2
Lagoons and marshes	-	56.0	-
Animals and waste	-	194.6	-
Land fills	-	122.0	-
Paddy fields	-	406.6	-
Fertiliser use	-	-	0.15
Total	4960	795	9.7

Table 5: Estimated emission of greenhouse gases from the energy sector

	Emission rate kT/yr		
	CO_2	CH_4	N_2O
Petroleum combustion	1389	0.17	-
Biomass combustion	11,557	12.46	-
Total	12,596	12.63	-

Water pollution

Pollution of waterways is a serious environmental problem faced by the world today. Water is essential for all life forms and for industry. Millions of people in the world die every year from water borne diseases such as cholera, typhoid, and bowel diseases and faecal contamination of drinking water is responsible for hepatitis and amoebic dysentery. Two thousand million people are at risk from water borne diseases and 3.2 million children die world wide each year from such diseases.

Water pollution in Sri Lanka results from domestic, industrial and agricultural activities. Less than 25% of all households in Sri Lanka have access to pipeborne water and lack of health education further aggravates these problems. Even pipeborne water provided by local authorities is not monitored for the presence of trace organic compounds such as pesticides and heavy metals. The major water pollutants affecting our water bodies are given in table 6.

Table 6: Major types of water pollutants with examples and their environmental effects.

Class of Pollutant	Example	Significance
Trace elements	Hg,Cd,Pb,Cr	health
Radionuclides	Pu	toxicity
Inorganic pollutants	nitrate, phosphate	eutrophication
Trace organic pollutants	polychlorinated biphenyls pesticides petroleum wastes(oil)	cancer
Sewage	human and animal waste	diseases, water quality pathogens
Organic phosphates	detergents	eutrophication
Heat	coolant water from power plants	fish population
Sediments	silting of lakes	reduced capacity for power generation

Lakes in Sri Lanka, such as the Beira lake and the Kandy lake are two of the most polluted water bodies in Sri Lanka with regular outbreaks of algal blooms arising from eutrophication. The increased organic content in water bodies depletes oxygen and affects fish populations. In a study[24] on the water quality of the two lakes at Nuwara Eliya, Lake Gregory and the Barrack's Plain reservoir, it was found that the dissolved oxygen content of these lakes is sometimes too small to sustain a reasonable fish population. The main cause of pollution is the discharge of raw sewage, hospital waste and vegetable waste direct into the feeder streams.

Pollution of the Kelani river and other water bodies

The Kelani river is the most highly polluted river in Sri Lanka which drains the most populated province in the country with many industries discharging both treated and untreated industrial effluents. The Central Environmental Authority lists 23 major industries along the river with 20 discharging effluent directly into the river or its tributaries. (table 7).

Domestic and industrial waste collected by municipalities and local councils is dumped either direct into the river or into garbage disposal sites close to the river. Seepage from the Orugodawatte garbage dumping ground of the Colombo Municipal Council feeds the Kelani river and this effluent is high in pathogenic bacteria, organic content and heavy metals. There are several textile factories discharging organic dye waste into the Kelani river downstream of Hanwella and some of these dyes may be cumulative poisons. The Colombo Municipality extracts Kelani river water and during chlorination, these organic compounds may be chlorinated producing carcinogenic chloroaromatic compounds. Long term accumulation of such chloroaromatic compounds is known to cause gastric cancers and perhaps kidney diseases.

Table 7 : Untreated industrial effluent outfall into the Kelani river

Industry	Effluent type
Pugoda textiles	Textile dye effluent
Plywood corporation	Glue mixtures
McCallum Brewery	Brewery waste (carbohydrates)
Ceylon Cold Stores	Bottlewash water, oil, grease, detergents
Pure Beverages Ltd.	Bottlewash water, oil, grease, detergents
Petroleum refinery	Petroleum effluent
Fertilizer corporation	Fertilizer effluent
Tyre corporation	Waste water
Ceylon Transport Board	Service station waste
Madampitiya sewage works	Domestic sewage
Leather tanning factory	Chromium salts
Ambatale water treatment plant	Organic waste
Rubber factories	acetic/formic acids, amino acids

A number of reports[25] on the water quality of this river are available for sites throughout the length of the river. In general pollution indicators such as BOD, NH_3 and NO_3^- show a regular increase from the origin of the river to the point of discharge into the sea. The heavy metal concentrations are high at Thotalanga where seepage water from the Orugodawatte garbage disposal site flows into the river. The mean concentrations recorded[26] were Pb(7.4 ppb) Cd(2.7 ppb), Cu(10.2 ppb), Sn(52.5 ppb) and Mn(650 ppb). Heavy metal concentrations (Cr,Pb,Zn and Cd) in the Beira and the Lunawa lagoon have been investigated[27] and they were found to be lower than the standards of the Central Environment Authority for industrial waste water. However, many people use this lagoon for washing and bathing and if the drinking water standards are taken into account, the lead concentrations are higher than the allowed values. High concentrations of lead most likely could arise from industries involved in recovering lead from old car batteries.

Table 8 : Selected water quality parameters of some water bodies.

Water body	DO (mg/l)	COD (mg/l)	BOD (mg/l)	Coliform (per 100 ml)	Total-N (mg/l)	Total P/(mg/l)	Zn(ppb)	Cd(ppb)	Pb(ppb)	V(ppb)
Kandy Lake	5.0-7.0	10-28	8.5-11.0	200-800	22-35	0.20-0.50	60-100	10-190	100-390	6-32
Lake Gregory	7.0-9.0	24-44	30-50	70-230	23-48	0.20-0.80	10-20	<10	-	-
Barracks Plain reservoir	0-0.3	30-250	12-30	>1000	30-50	1.4-1.8	70-100	<10	-	-
Meda-ela	3.0-3.6	40-60	7.8-8.2	3000	15-18	1.3-1.8	-	10-310	20-850	6.5-45
Negombo lagoon	3.0-5.0	-	18-40	6000	-	0.01-0.28	10	20	-	-
Bolgoda lake	5.5-8.0	-	-	-	-	0.04-1.02	-	-	-	
Hamilton canal Beira lake	3.5-6.0	-	1-30	2300	-	-	10	20	-	-
Kelani river	7.3	1.5-2.0	3.6-5.5	5000	7.0-8.0	0.02-0.03	52.5	2.7	7.4	
Mahaweli river	7.0-7.5	8.0-10.0	3.5-4.7	2200	5.0-10.0	0.50-1.00	20	<10	-	-

Pollution of our lakes and lagoons is extensive in terms of organic load given out by domestic and industrial refuse. Very often household refuse collected by Municipalities and Pradeshiya Sabhas is directly dumped into rivers. Coliform bacterial counts often exceed the permitted values. Some examples of highly polluted lakes include; Beira lake, Kandy lake, Bolgoda lake, lagoons at Negombo and Lunawa, Lake Gregory and Barrack's Plain reservoir at Nuwara Eliya. Some available water quality parameters for these water bodies are given in Table 8. It must be stressed that the data in this table come from several independent studies and should be viewed with caution. These values give only a rough estimate of the water quality status since there is a wide variation in the values obtained depending on the season, time of collection of samples and the location of the sampling points. Although the drinking water quality standards are often exceeded in the coliform counts and COD values, the standards for industrial waste water are rarely exceeded in these water bodies. In the broadest sense, the dissolved oxygen content can be used as an indicator of the extent of pollution in a water body (table 9). According to this index the Meda-Ela of Kandy, Negombo lagoon and the Hamilton canal can be considered as highly polluted, Kandy lake to be moderately polluted and the Kelani and the Mahaweli rivers slightly polluted. The Barrack's Plain reservoir is actually not a reservoir at all at the present time due to extensive human activities having reduced it to a mere pool of water at its very end. The dissolved oxygen in this water body is too low for any form of aquatic life to survive.

Table 9 : Relationship between water quality and the dissolved oxygen (DO) content.

Water Quality	Amount of Dissolved oxygen (mg/l)
Excellent	8.0-9.0
Slightly polluted	6.7-8.0
Moderately polluted	4.5-6.0
Highly polluted	<4.5

Heavy metal pollution exceeding safe limits have been reported[26] from Kandy lake where the average levels of Pb, Cd and V are 150, 80 and 15 ppb respectively. These certainly exceed the CEA standards of 100 ppb for Pb and 10 ppb for Cd. However the validity of these values has been questioned.[25] Similarly the Meda-Ela in Kandy is reportedly excessively contaminated with heavy metals (Table 8).

Pollution of other rivers

The accumulation of oxygen demanding wastes adversely affects aquatic life. The Walawe river is polluted from Embilipitiya downstream owing to the discharge of untreated black liquor wastes from the paper factory. The discharge of textile dyes to the Maha-Oya at Thulhiriya is another example. The water in these cases is unsuitable for bathing and even animals are at risk from drinking such contaminated water.

Algal toxins

The algal blooms reported in the Beira and Kandy lakes can be attributed to excessive amounts of raw sewage discharged directly into these water bodies. This provides organic matter, nitrates and phosphates which stimulate the growth of blue-green algae such as *Microcystis*. These nutrients enter the water bodies also due to industrial and agricultural activities. Several Mahaweli reservoirs also experience algal blooms owing to excessive fertilization of vegetable farms and tea estates upstream. The addition of blue green algae increases the organic content of a reservoir thereby depleting it of vital oxygen required for aquatic life and this may result in lower fish populations of these reservoirs.

Some blue-green algae produce toxins which can have serious health implications for humans, fish and other animals like cattle. Three main types of toxins have been identified; hepatotoxins, (liver damage, gastrointestinal problems), neurotoxins (muscle tremor, paralysis) endotoxins (skin rashes, eye irritation and other allergic reactions). *Microcystis* produces microcystin LR having a relative toxicity 1000 times greater than cyanide. Occasional occurrences of algal blooms have been reported from the smaller tanks in the North Central province and it is important to educate the local population about the health hazards of using such contaminated water for drinking, bathing and for use by cattle.

Pesticides

Large quantities of pesticides are increasingly used in Sri Lanka to sustain agriculture. Every year around 3000 tons of pesticides are sprayed over the environment and most of these finally end up in our waterways. Monitoring of pesticides in drinking water is absolutely essential to determine such contamination since these tend to accumulate in the fatty tissues of humans and can have long term health effects. Several pesticides with concentrations in the parts per billion (ppb) range were found[28] in Mahaweli river water at Peradeniya. The technique employed for this study involved the use of solid phase cartridge type concentrators and gas chromatography. The origin of these pesticides is probably the intensively cultivated vegetable areas of Nuwara Eliya.

Very few analytical results on the contamination of fruits and vegetables with pesticides have been reported from Sri Lanka. In an earlier study, Ramasundaram et al.[29] determined chlorinated hydrocarbon residues in fruits, vegetables, fruit juices, tobacco and tea using gas chromatographic techniques. Both DDT and BHC were detected but below the WHO/FAO recommended residue tolerance values. In another study[30], it was found that greengram and cowpea from the Kurunegala district were contaminated with malathion (0.005-6 ppm) and pirimiphos methyl (0.002-4.85 ppm). Some food products exported to the USA had low levels of chloropyrifos and endosulfan but within the accepted tolerance limits. In a related study, it was found[31] that green chillies were contaminated with low levels of these two pesticides but well below the tolerance limits stipulated by FAO.

Nitrate

Pollution due to excessive amounts of nitrogenous species such as ammonium, nitrite and nitrate is very common in areas of high population density and excessive fertiliser usage. In a study[32] on the nitrate concentrations from shallow water wells in the Kandy district, it was found that the average nitrate content was around 2.5 ppm which is well below the WHO recommended value of 50 ppm. However, the validity of this standard as applied to a tropical country such as Sri Lanka is debatable since people consume far greater quantities of water than in a temperate country. In one well[32] at Galagedera, in the Kandy district, the concentration of nitrate was around 23 ppm and similar high values of nitrate have been found from well waters at Maharagama where septic tanks are in close proximity to deep water wells. Nitrate is variously associated with diseases like methaemoglobinemia, gastric cancer, thinning of blood vessels, aggressive behavior and hypertension. None of these have been conclusively established from scientific studies in Sri Lanka although some suggestions have been made that the high nitrate in drinking water in the Jaffna peninsula is responsible for abnormally high incidence of gastric cancer in this area.

Pollution due to heavy metals

Pollution due to heavy metals can arise due to a number of reasons. Discharge of industrial effluents, deposition of motor car exhaust fumes and geological features of the soil are some of these factors. Arewgoda[33] found that well waters around Kelaniya where a number of brass foundries are in operation are contaminated with Pb (0.095 ppm), cadmium (0.065 ppm) and zinc (10.91 ppm).

Chromium

Chromium is present in soil at concentrations ranging from 1-250 ppm and in water at levels ranging from 1-10 mg/l. It is important to animal health and is considered to be a co-factor for the action of insulin. Chromium in coal is reported to be around 60 mg/kg and between 27.5-60.0 mg/kg is found in Portland cement and hence cement dust could significantly contribute to chromium in such an environment. Asbestos contains 1500 mg/kg of chromium and inhaling asbestos dust is hence harmful not only due to its carcinogenic activity but also due to other toxic effects of chromium. Welders are exposed to welding fumes containing 2-4% water soluble Cr(VI) and 0.2-2% water insoluble Cr(III) and metallic fumes. Chromium has been indicated as a cause of lung cancer and welders are particular prone to having lung and urinary cancers owing to chromium.

Chromates are generated in chromium plating, anodizing and other metal finishing operations in Sri Lanka where the disposal methods are generally of a very primitive nature. Electroplating wastes may also inhibit biological sewage treatment by killing beneficial bacteria. Chromium compounds irritate the skin and dermatitis amongst the workers at the government leather factory has been reported[34] as for back as 1947. In Sri Lanka basic chromic sulphate is used in the leather tannery at Kelaniya where the effluent is discharged to the Kelani river. This has caused numerous environmental problems in the past and the occasional fish kills of the Kelani river have been largely attributed to chromium poisoning. The presence of excessive chromium[35] in green leafy vegetables grown in the Kelaniya area has caused considerable alarm where concentrations up to 200 ppm chromium have been observed. However epidemiological studies on the long term health effects of chromium toxicity have not been carried out in Sri Lanka.

Zinc

Zinc contamination occurs mainly in the manufacture of brass in open crucibles where the sand used in moulds is generally dumped on open ground. The soil gets heavily contaminated with zinc, copper, lead and cadmium which eventually get washed by rain water. In Kelaniya, where there are a large number of brass foundries, metal fume fever is a common health problem of workers. Vegetation too gets affected and no vegetable or flower plants grow on such heavily contaminated soils.

Mercury

Recovery of gold & silver from jeweller's waste is an occupation of a number of families in the Kelaniya area where mercury or lead is used to form alloys of these precious metals. Absorption of mercury and lead in the vapour phase affects the health of these families with symptoms such as tiredness, abdominal discomfort, anaemia and behavioral changes in children. The mean urinary mercury level of families engaged in gold recovery was 0.5141 ppm which is significantly higher[36] than in the control group where the mean level was 0.0734 ppm.

Lead

Concentration of lead in exhaust fumes of petrol vehicles is typically 2000-10,000 $\mu g/m^3$. Tetraethyl lead added as an anti-knock agent to petrol reacts with other additives such as dichloroethane and dibromoethane giving lead chloride and lead bromide. These get deposited on roadside plants and on the soil. Household dust is the major source of contamination indoors while people on the street may inhale freshly generated lead compounds before deposition and agglomeration. Street children are particularly vulnerable and it has been shown that lead inhalation gives rise to neuropsychological disorders and reduces learning abilities. In severe cases even mental retardation is possible and most countries have programmes to phase out the use of lead in petrol. Blood lead levels of family members involved in recovering gold from shop sweepings often exceed 40 μg/dL.[33] In a related study, Dissanayake and Weerasooriya reported[37] lead levels as high as 14 mg/g in human hair of inhabitants living close to highways in Kandy and this can be attributed directly to the high degree of air pollution from motor vehicles. In a study of the blood lead levels of some categories of people who spend a considerable time on the streets, Arewgoda[38] found that traffic policemen had the highest lead levels (53 μg/dL) followed by three- wheeler drivers (15 μg/dL) and street vendors (12.6 μg/dL). The control group in this case had a lead level of 8.8 μg/dL. Lead levels beyond 15 μg/dL are detrimental to human health while it is hazardous to have levels beyond 40 μg/dL.

Aluminium

Aluminium toxicity due to leaching of minerals due to acid rain is largely blamed as the cause for depletion of fish from Scandinavian lakes and also for the destruction of alpine forests in Germany. Acid rain occurs in many parts of Sri Lanka[39] and the effects of leached aluminium on flora and fauna have not been properly assessed. In an isolated instance, Pathiratna et al.[40] reported that wells within a 2 km^2 area around Ranala had pH values of 3.57-4.88 well below the pH range suitable for drinking water. The aluminium content in these wells was found to be as high as 1100 $\mu g/m^3$ and acid drainage from the sulphuric acid plant at Ranala which operated for a brief period is the probable cause for this type of pollution.

Cadmium

Cadmium is almost always associated with zinc and the zinc to cadmium ratio plays a vital role on the effect of zinc on living organisms. Excessive cadmium adversely affects humans and the consumption of cadmium rich rice by humans caused the extremely painful disease in Japan commonly referred to as the Itai-Itai disease.

Cadmium is not considered as an essential element but accumulates mainly in the kidneys of the human body, from the environment through food, water and cigarette smoke. This has been considered as a factor contributing to hypertension, specially among heavy cigarette smokers. Cadmium contamination of exported Shitake mushrooms has been reported[41] with values in excess of 0.05 mg/kg. The growth medium for these mushrooms was rubber wood sawdust. The origin of cadmium in this case has been found to be the imported phosphate fertilisers which contained around 5-15 mg/kg of cadmium. Interestingly, the same authors found that local Eppawela apatite phosphate contained no detectable cadmium.

Detoxification of polluted waters

Development of low cost methods for removing heavy metals in industrial effluents has received the attention of scientists in Sri Lanka. Chemical precipitation has been traditionally used for this process and decaying leaves have been used for removal of metals such as Al, Ni, Pb and Cd from aqueous solution.[42] Activated carbon too has been used to remove heavy metals as well as organic contaminants.[43] Brick particle filters used for the removal of excessive fluoride in water also removed heavy metal ions like Cr, Mn, Fe, Co, Cu, Zn, Cd and Pb from their dilute solutions. Priyantha et al[44] found more than 90% removal of metal ions from industrial effluent samples using brick particles. Another material reported by the same authors[45] is sawdust from *Albizzia odoratissima*(mara) which removed organic dyes as well as heavy metals like Cu, Zn, Cd. The same authors have reported[46] the use of glass columns packed with burnt brick particles for the removal of lead from water. The removal of phosphate by dolomite has been reported by Priyantha and co-workers[47] where the removal of up to 60% of phosphate in polluted water samples was observed. The adsorption of coloured industrial effluents such as textile dyes on ball clay has been reported by Priyantha et al.[48] where the adsorption of dyes such as malachite green, methylene blue, crystal violet, congo red and commercial textile dyes on ball clay has been established. While the methods described above refer to concentration of pollutants in a suitable form to be discarded or buried, they do not necessarily convert the pollutants into inactive forms or reuse the materials in a useful way. Disposal of some toxic metals in concentrated forms in itself may have its own inherent problems.

The use of semiconductors such as titanium dioxide for the complete photodegradation of organic pollutants is well established. Several investigations using TiO_2 supported on glass plates or polythene films to degrade pesticides such as chloropyrifos[49], methamidophos[50] have been reported. Tennakone et al. in a series of papers have reported the photodegradation of textile dyes[51], paraquat[52] and the removal of lead[53] and mercury[54] from waste water on TiO_2. Some aquatic weeds have the ability to accumulate heavy metal ions and there have been a number of studies on the bioremediation of heavy metal pollutants using aquatic weeds. The use of *Hydrilla*[55], *Salvinia* and *Eichornia*[56] for this purpose has been demonstrated. Priyantha et al[58]. reported that *Pistia stratiotes* (water lettuce) is capable of removing about 35% of the metal ions from dilute solutions containing the metals; Mg,Ca,Mn,Fe,Co,Cu,Zn and Pb .

CONCLUSION

There is significant environmental pollution in Sri Lanka with increasing economic prosperity and increasing population. Air pollution in major cities such as Colombo is a major health hazard specially with respect to ozone and fine particles. Environmental action plans to control air pollution are an urgent necessity. Our waterways are getting increasingly polluted by human sewage which has a direct impact on human health. There is a need to monitor pesticides in drinking water as they may have long term health effects such as cancer. There is also the possibility of food contamination through pesticides sprayed on vegetables and fruits close to the time of harvesting. Isolated instances of heavy metal pollution by lead, chromium and mercury have been reported.

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