Report on Air Quality and Health Impact Assessment Project

Consultant: Dr. Sumal Nandasena
MBBS, PGD (Sociology), MSc (Community Medicine), MD (Community Medicine)
Specialist in Public Health and Community Medicine

Table of Content

Table of Content iii
List of Tables vi
List of Figures vii
Abbreviations viii
Introduction to the project 9
Inception workshop 10
Profile of the participants from the health sector 10
Summary of the key presentations at the workshop 12
Presentation on objectives of the program 12
Introduction of the UNEP Project on Air Quality assessment for health and environment policies in Africa and Asia-Pacific 12
Air Quality Monitoring, Management Policy Development and Identification of Data Sources 13
Health Impacts of Air Pollution Importance of Linking the Air Quality and Health 13
Introduction to the group work 13
Guide questions for group: Stakeholders and health data source mapping 13
Guide questions to link health and air quality data 14
Summary of presentation based on the discussion of health sector groups 14
Group 3- Stakeholders and Health data source mapping 14
Group 4 - Linking health data and air quality data 15
Concluding remarks of the workshop 15
Introduction: air quality and health 18
Definition of air pollution 18
History of air pollution studies 18
Burden of air pollution 19
Types and sources of air pollutants 19
Variability of outdoor and indoor air pollutants 20
Exposure variability and vulnerability to air pollutants 21
Health effects of air pollutants 21
Respiratory health effects of air pollutants 22
Non-respiratory health effects 24
Health data sources in Sri Lanka 25
Electronic Indoor Morbidity and Mortality Register (eIMMR) 25
Strengths 25
Weaknesses 25
Mortality data from the Registrar General Department 25
Strengths 25
Weakness 25
Data from the other national surveys 26

Strengths ... 26
Weakness ... 26

Health sector in Sri Lanka ... 27
Public (e.g., government) vs. private allopathic care ... 27

Methodology ... 31
Health outcomes for data analysis ... 31
Analysis method of eIMMR data base ... 31
ICD (International Classification of Diseases) ... 32
ICD codes of the health outcomes ... 33
Statistical analysis ... 34
Mortality data from the registrar general department ... 36
Data from the other national surveys ... 36

Results ... 37
Component 1: Association of data from the Electronic Indoor Morbidity and Mortality Register and passive sampler data from the National Building Research Organization ... 37
Descriptive Statistics of the Electronic Indoor Morbidity and Mortality Register ... 37
Adjustment for total population seek medical care from government hospitals in the year 2017 in the Colombo district ... 41
Predictions of deaths and admissions related to air pollution related diseases in NHSL in the year 2017 ... 41
Comparison of deaths due to the air pollution related diseases and the NO_2 and SO_2 concentrations ... 44
Component 2: Association of data from Registrar General Department and passive sampler data from the NBRO ... 47
Component 3: Association of data from the Electronic Indoor Morbidity and Mortality Register and Continuous data from the Central Environmental Authority (CEA) ... 50
Air quality data from the automated monitor located at the premises of Central Environmental Authority ... 50
Air quality data from the automated monitor located at Kandy ... 52

Discussion ... 59
Uniqueness of the study ... 59
Results summary, interpretation and assumptions ... 59
Reported NO_2 and SO_2 concentration vs. WHO guideline values ... 61
Reported $PM_{2.5}$ concentration vs. WHO guideline values ... 63
Advanced statistical modelling of $PM_{2.5}$ concentration at the city of Kandy ... 64
Clean air action plan –2025 and prioritization of the activities ... 65
Air quality monitoring in Sri Lanka ... 65
Indoor air pollution ... 66
Confounding factors/variables in the assessment ... 66
Limitations ... 67
Study design: ... 67
Exposure misclassification: ... 67
Limited number of districts: ... 68
Unavailability of continuous monitoring data of air quality: ... 68

Community based deaths are not counted: ... 68
Overlapping of the patients attend to the hospitals: ... 68
Limited number of passive samplers ... 68
Hospital data (i.e., eIMMR) sources Vs. registrar general department data ... 68

Conclusions and recommendations for policy implications ... 69

Conclusions ... 69

Recommendations ... 71

Air quality monitoring should be strengthened ... 71
Clean Air 2025 action plan should be revisited and modified ... 71
Passive samplers monitoring network should be covered the larger geographic area and should be linked with the automated air quality monitoring ... 72
Air quality standards should be revisited and should be revised with expert opinions ... 72
Future epidemiological health research should be planned to overcome the gaps of the present study ... 72

References ... 73

Annexures ... 75

Annexure 1 ... 76

Annexure 2 ... 78

Annexure 3 ... 81

Annexure 4: ... 82

Annexure 5: ... 83

List of Tables

Table 1:Participants profile represent the health sector 11
Table 2 Stakeholders and their role in the health impact assessment. 16
Table 3:Adverse respiratory health effects due to air pollution 22
Table 4: Number of admissions and outpatient visits for public and private hospitals: Number of admissions and outpatient visits for public and private hospitals, 1990–2009 28
Table 5:Variables to be obtained from the eIMMR data base 32
Table 6: The ICD codes to be used for the data analysis 33
Table 7: Passive sampler air quality level (Monthly average value for SO_2 and NO_2) available cities and period 34
Table 8: Gender distribution of government hospital admissions in the selected districts 38
Table 9: District distribution of total admissions of government hospitals in year 2017 in Sri Lanka 38
Table 10: Disease categories of admitted patients 38
Table 11: Discharge mode of the patients... 39
Table 12: Cross-tabulation of selected diseases and the discharge mode.................................... 40
Table 13: Population adjustment for selected districts 41
Table 14: Hospitals in Colombo which are not considered in the estimation of admissions in National Hospital in Sri Lanka 42
Table 15: Average admissions and deaths in the District of Colombo 42
Table 16: Estimation of admissions and deaths of NHSL based on the predictions of Colombo District 44
Table 17: Comparison of death rate and air quality levels in selected districts 44
Table 18: Total crude death rate and air quality of selected districts 47
Table 19:Summary of air pollutant concentrations during the monitored period (24-hour concentration values) - Colombo 51
Table 20:Descriptive statistics of the hospital admission for the period of air quality availability (from 12.12.2018 to 2019.02.28) 52
Table 21:Summary of air pollutant concentrations during the monitored period (24-hour concentration values) - Kandy 53
Table 22:Descriptive statistics of the hospital admission for the period of air quality availability (12.12.2018 to 02.04.2019) 53
Table 23: Relative risk of different $PM_{2.5}$ concentration for non-respiratory disease hospital admissions 58
Table 24: Summary of excess deaths (per 100,000population) for increase of NO_2 and SO_2 based on two sources of health data 61
Table 25: Comparison of reported air quality levels with the WHO guideline value and the Sri Lankan standard 62
Table 26:Sri Lankan air quality standards 62
Table 27: Comparison of $PM_{2.5}$ and PM_{10} with the Sri Lankan and WHO guideline values (24-hour average) 63

List of Figures

Figure 1: Major causes of deaths in Sri Lanka (Adapted from Institute of Health Metrix and Evaluation) 19
Figure 2: Air pollution - health effects pyramid (Adapted from the WHO report on quantification of the health effects due to exposure to air pollution, (WHO 2000)) 23
Figure 3: Sample sheet of the data for selected variables (hospital name is deleted due to ethical reasons) 33
Figure 4: Districts selected for the analysis based on the availability of air quality data (Dark green colour) 35
Figure 5: Components of the study 37
Figure 6: Correlation between death rate and NO_2 concentration 45
Figure 7: Correlation between death rate and SO_2 concentration 46
Figure 8: Crude death rates and the NO_2 concentrations (Year 2017) of the selected districts 47
Figure 9: Crude death rates and SO_2 concentration (year 2017) of the selected districts 48
Figure 10: Crude Death Rate (2017) and average NO_2 concentration (2013 to 2017) 49
Figure 11: Crude Death Rate (2017) and average SO_2 concentration (2013 to 2017) 49
Figure 12:Location of the Air Quality monitor and major hospitals 51
Figure 13: Relationship of the admissions of the respiratory diseases and the $PM_{2.5}$ 24-hour concentration 52
Figure 14:Relationship of the admissions of the respiratory diseases and the PM2.5 24-hour concentration – Kandy 54
Figure 15: Three-dimensional model output showing the relative risk, particulate matter concentration and lag time of exposure for non-respiratory hospital admission. 54
Figure 16:Three-dimensional model output showing the relative risk, particulate matter concentration and lag time of exposure for respiratory hospital admission 55
Figure 17: $PM_{2.5}$ concentration and relative risk 1 - 4 days lag for non-respiratory disease concentration (X axis represents the $PM_{2.5}$) 56
Figure 18:$PM_{2.5}$ concentration and relative risk 1 - 4 days lag for respiratory disease concentration (X axis represents the $PM_{2.5}$) 57
Figure 19: Disease categories considered in the data analysis 59
Figure 20: Graphical summary of number of excess deaths for the increase of $10\mu g/m^3$ of NO2 and SO2 61
Figure 21: WHO guidelines and the Sri Lanka standards for 24-hour $PM_{2.5}$ concentration 64
Figure 22: Daily $PM_{2.5}$ concentration cut-off over the $50\mu g/m^3$ 65
Figure 23: Relationship of the exposure to air pollution, health impact and the confounding factors 67
Figure 24: Key Recommendations 71

Abbreviations

CDR	Crude Death Rate
CEA	Central Environmental Authority
CO	Carbon Monoxide
eIMMR	Electronic Indoor Morbidity and Mortality Register
GIS	Geographic Information System
ICD -10	International Classification of Diseases – 10th Revision
LAMA	Left Against Medical Advice
LMICs	low- and middle-income countries
NBRO	National Building Research Organization
NHSL	National Hospital of Sri Lanka
NO_2	Nitrogen Dioxide
O_3	Ozone
OPD	Out Patient Departments
PM	Particulate matter
PMCU	Primary Medical Care Units
RGD	Registrar General Department
SO_2	Sulfur Dioxide
UNEA	UN Environment Assembly
UNEP	United Nations Environment Program
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

Introduction to the project

Health impact of the air pollution is necessary to develop policies to control emissions of pollutants and reduce health risks. With this understanding, Ministry of Mahaweli Development of Sri Lanka in partnership with the United Nations Environment Program (UNEP) has initiated the project entitled “Air Quality Assessment for Health and Environmental Policies”. The project has the objectives (1) to enhances the capacity to strengthen and use data and information to assess air pollution levels, (2) to support development of evidence-based policies on air quality and health and (3) to bring together knowledge from environment and health domains.

Under this project, the Ministry of Mahaweli Development and Environment will carry out a detailed assessment of the evidence base on air quality and related health issues in order to review existing national action plan on air quality and related legislation and to identify policy interventions to minimize health impacts. As the initial step of the project, it was necessary to conduct an inception meeting with stakeholders to discuss details of the implementation of the project and to identify data to be collected for the air quality and health impact assessment.

Inception workshop

Workshop was conducted based on pre-prepared agenda. Agenda is annexed with this report. Following is a brief description of different activities and the content of the workshop.

Profile of the participants from the health sector

Range of officers from Ministry of Health, Sri Lanka, Leading Universities in Sri Lanka, Department of Census and Statistics, Sri Lanka and several other institutions were represented the health sector of the workshop. All the officers were carefully selected and invited considering importance of the expertise. Following table gives the participated resource person, their designation and institute.

Table 1:Participants profile represent the health sector

	Name	Designation	Institution
1	Dr. Abusaheed	Registrar in Bio Informatics	Postgraduate Institute of Medicine, University of Colombo, Sri Lanka.
2	Dr. Chaminda Weerabadana	Registrar in Bio Informatics	Postgraduate Institute of Medicine, University of Colombo, Sri Lanka.
3	Dr. Inoka Suraweera	Consultant Community Physician	Directorate of Environmental and Occupational Health, Ministry of Health, Sri Lanka
4	Dr. Nalinda Wellapuli	Medical Officer	Management Planning Unit, Ministry of Health, Sri Lanka.
5	Dr. Niroshini Adikaram	Registrar in Community Medicine	Postgraduate Institute of Medicine, University of Colombo, Sri Lanka
6	Dr. Shrinika Weliyange	Senior Lecturer in Community Medicine	Department of Community Medicine, Faculty of Medicine, University of Colombo, Sri Lanka
7	Dr. Verginie Mallwaarachchi	National Professional Officer – Non-communicable Diseases	World Health Organization, Country Office, Sri Lanka
8	Mrs. Hasinthi Swarnamali	Research Assistant	National Institute of Health Sciences, Ministry of Health, Sri Lanka
9	Mrs. Sajeewa Kodikara	Head, Medical Statistics Unit, Department of Census and Statistics, Sri Lanka.	Medical Statistics Unit, Department of Census and Statistics, Sri Lanka.
10	Mrs. Sardha Lasanthi	Senior Statics Officer	Medical Statistics Unit, Department of Census and Statistics, Sri Lanka.
11	Prof. Dhammika N. Magana-Arachchi	Research Professor	National Institute of Fundamental Science, Sri Lanka
12	Prof. N.K. Gunasekara	Head and Professor, Specialist in Geographic Information System	Faculty of Medicine, University of Kelaniya, Sri Lanka

Summary of the key presentations at the workshop

Presentation on objectives of the program

Welcome and the objectives of the program were presented by the Mr. Sugath Darmakeerthi, Director of the Air Resource Management and National Ozone Unit, Ministry of Mahawali Development and Environment. He explained the importance of generating air quality data in various locations of the country for policy making and importance of undertaking preventive measures for health impact of the air pollution. He further emphasized that this project was implemented to take relevant precise data using accurate measuring equipment and procedures.

Introduction of the UNEP Project on Air Quality assessment for health and environment policies in Africa and Asia-Pacific

The presentation by Mr. Bert Fabian, representative from United Nations Environment Program (UNEP) gives the scope of the program. Since his presentation gives orientation to the project, more details of his presentation are included in this report. He introduced the UNEP project on Air quality assessment for health and environment policies in Africa and Asia-Pacific region. First, he briefed on how air pollution become as a silent killer and therefore its importance of improving air quality in Asia Pacific region. In his presentation, he mentioned that the material footprint per unit of Gross Domestic Production in Asia-Pacific remains twice as intensive as the world average and per capita consumption of natural resources increased by 53 per cent between 2005 and 2015 while resource efficiency has been declining in the region since the beginning of the century. With regards to the health burden of air pollution, four billion people, or 92% of the population across the Asia Pacific region are exposed to unhealthy air pollution. He mentioned that although some succession was achieved in some countries to reduce air pollution, there are some more to improve. According to him, if current policies are introduced and enforced, air quality in 2030 will be no worse than in 2015 even with increased population and rapid urbanization. But it will still leave 4 billion people exposed to dangerous air pollution. Therefore, further action is needed to move towards WHO air quality guidelines. He enlightened that it requires to reduce emissions that lead to the formation of $PM_{2.5}$ and ground-level ozone. Mr. Bert explained the impact of air pollution in terms of food security, economy and climate. And then, he talked about UN Environment Assembly (UNEA) which is the highest-level decision-making body on the environment and having universal membership of 193 UN Member States and its response to the UNEA Resolution on Air Quality. This response was shown by widening the activities to support with AQ action focused on capacity building, assessment, awareness and cooperation. Here, activities have been initiated throughout UN Environment Divisions and Regional Offices and first region of focus is Asia and Africa to assess and enhance capacity to assess impacts of air quality on health.
Mr. Bert then introduced the objectives, outputs, scope and expected outcomes of the projects. First aim is the enhancing capacity to strengthen and use data and information to assess ambient air quality and support the development and implementation of evidence-based policies on ambient air quality and health. Second aim of the project is: addressing the gaps in knowledge base on ambient air quality and health impacts and connects the two areas, in support of coherent policy making by recommending policy action based on the project outcome to encourage positive impact on people's health. Outputs are assisting countries to identify available air quality and health related information, producing assessments of air quality and health for target countries and building capacity to empower stakeholders in the target countries to generate, access and use environmental information for policy action. This project scope on three countries in Africa (Benin, Botswana, Ethiopia) as well as three countries in Asia (Mongolia, Sri Lanka, Thailand).

Expected outcomes are making target countries capable to collect and report data, information and knowledge on the air quality and health nexus, and share these on open access platforms and to produce evidence-based policies on air quality and health.
He further clarified policy objective, scope of assessment and lead partner of the Thailand and Mongolia.

Air Quality Monitoring, Management Policy Development and Identification of Data Sources

Presentation on "Air quality monitoring, management policy development and identification of data sources" was done by Mr. H.D.S Premasiri, Senior Scientist, National Building Research Organization. In brief, he explained the importance of air quality, different techniques of air quality monitoring methods in Sri Lanka and the importance of identify the sources of air quality in Sri Lanka.

Health Impacts of Air Pollution Importance of Linking the Air Quality and Health

Dr. Sumal Nandasena, Consultant Community Physician from Ministry of Health presented about "Health Impact of Air Pollution and Importance of linking the air quality and health". He briefly explained about epidemiology of air pollution and its scientific basis. Further he briefed the Sri Lankan burden of diseases.

Introduction to the group work

With this background, participants were divided into four groups. Identified four groups are as follow.
1. Air Quality: Stakeholders and data source mapping – **Group 1**
2. Air Quality: Stakeholders and data source mapping- **Group 2**
3. Stakeholders and Health data source mapping- **Group 3**
4. Linking Health and air quality data – **Group 4**

The key questions to answer in the group work was presented to the group in view of guiding the discussions with an aim. However, it was stressed that the discussion and the presentations should not be limited to the guide questions.

Guide questions for group: Stakeholders and health data source mapping

1) Data sources of indoor morbidity/health outcomes
2) Upper respiratory system
    a. Lower respiratory system
    b. Ischemic Heart Diseases
    c. Diabetes
    d. Strokes
3) Data sources of outdoor morbidity/health outcomes:
    a. Upper respiratory system
    b. Lower respiratory system
4) How to obtain the Private sector patient information?
5) What is the nature of data?
6) Challenges of obtaining data?
7) Administrative issues of obtaining data?

8) Any other important issues?
9) How to overcome the issues?
10) Possible policy options to overcome issues?

Guide questions to link health and air quality data

1) What are the possible options to link air quality and health data.?
2) What are the limitations of linking data?
3) Any other important issues?
4) How to overcome the issues?
5) Possible policy options to overcome the issues?

Summary of presentation based on the discussion of health sector groups

At the end of the group discussion, a participant from both groups delivered a presentation and a discussion was followed the presentations. Brief description about the presentation and the group discussion is given below.

Group 3- Stakeholders and Health data source mapping

Patient admitted to government hospitals data can be gathered using electronic Indoor Morbidity and Mortality registers. Almost 90% of patients admitted to the government hospitals can be accessed through the electronic data bases. Some private sector hospitals (e.g.: Asiri group, Hemas Thalawathugoda), are also connected to the electronic data bases. However, it is a small propotion of the private sector hospitals.

The data bases are maintained under the Medical Statistics Unit of the Ministry of Health, Sri Lanka. They can be centrally obtainable from the Medical Statistics Unit. Summary data is published regularly as the Annual Health Bulletin of Ministry of Health, Sri Lanka. Individual records are shared with authorized parties. This information may have certain challenges, as it does not verify the location of exposed to the air pollution since the patients may by pass the hospitals. Usually patients by pass some local hospitals and attend major hospitals such as "General Hospitals". One of the remedial measure could be remove this major hospital information and limit the analysis to hospitals such as "Base hospitals" and "Divisional Hospitals". They will represent the local area exposure and minimize the miss classification.

However, data on outpatient departments are scarce. Only routinely available data is the number of patients from the government hospitals. However, it is estimated that only about 40-50% of patient get the treatment from government hospitals while the rest take the treatment from private sector. Newer strategies, neither well popular not widely available are emerging such as the electronic systems. This is known as Health Information Management System. Since this data is not centrally located, that can be collected only locally if available from the institutions.

In some cases, accessing the data bases warrant ethical clearance obtaining at institutional level. At the same time, quality data acquisition from private sector will be a one of the challenges. However, some discussions were already done in detail at many forums to overcome these issues, for an instance, Expert panel discussed to improve the data from private sector at the Sustainable Development Goals steering committee. In addition to that, there is a National Policy on Health Information to mitigate such issues, which can be found in following link, http://www.health.gov.lk/enWeb/Pub_Opi/National%20Health%20Information%20Policy_English_v_14_04_2016.pdf).

Furthermore, the health outcomes data can be collected from surveys such as Demographic and Health survey, National Survey of Self-Reported Health, 2014 which occupied module of Labor Force Survey which consist of 25000 housing units and conditions of stroke, ischemic heart disease and asthma.

http://www.statistics.gov.lk/social/National%20Survey%20on%20Self-reported%20Health-2014.pdf

Registrar General Department gives cause of deaths or mortality records and ICD codes (International Classification of Disease) to identify the clinical entry. However, delaying in make data availability or data disseminating is a big issue in Sri Lanka (currently available 2013 data). There is approximately 35% of hospital deaths and the rest is at the residence. There is a quality issue in data obtaining in community deaths.

Group 4 - Linking health data and air quality data

Another group discuss the method of linking the air quality data and the health data. The group noted the fact that there may be challenges in obtaining the permission for accessing the data bases of both health and the air quality. First, prior permission should be taken to obtain the secondary data. Not having the complete representative data bases of health as well as air quality limit the quality of data.

Since the data is limited, novel techniques need to implement to assess the health impact. Since the continuous monitoring stations are not available, other data sources could be use. One method could be interpolation of available air quality data and estimate the air quality levels of the entire country. Then the available data from the health outcome can be overplayed with the interpolated air quality levels.

In addition, it should be assessed the method of using the different software such as SIM – air and BEN map for this purpose.

Concluding remarks of the workshop

The workshop was assisted to initiate the project. Furthermore, discussions made in the workshop gives the insight for source of health data and methods to link the health data and the air quality data. Key sources of the health outcomes are the electronic Indoor Morbidity and Mortality Register, survey results from Department of Census and Statistics and Health Information Management Systems (if available) of the hospitals. However, it is understood that there are limitations in the data available in both health and air quality. Perhaps it is necessary to identify novel methods to assess the impact of health from the air pollution. Possibly, Geographic Information System and the newer software will have the importance use in this endeavor.

Stakeholders and their role in the project

As per discussions made based on the inception workshop, stakeholders of the health data were identified. It was noticed that the health data itself cannot use for air quality and health impact assessment, thus it was necessary to have covariates (i.e., confounding factors) since it may affect by several non-health factors. As an example, it is necessary to balance for the socioeconomic status of the population based on the geographical distribution of the data source.

Table 2 Stakeholders and their role in the health impact assessment.

	Stakeholder	Role in the project and the remarks
1	Medical Statistics Unit and the resource person familiar with the data bases, Ministry of Health	The key health data source provider. The large data source which include the data from almost all hospitals in Sri Lanka. However, it is necessary to refine the data as the project needs and the staff of the Medical Statistics Unit will have to dedicate considerable time on cleaning and streamline the data as the project needs.
2	Survey department of Sri Lanka	Digital maps are developed by the Department of Sri Lanka is a key data source for the mapping techniques. The maps are sold from the department. Although the staff of the department is not involved, the maps developed by the department will be used for the techniques in the Geographic Information System (GIS)
3	Department of Census and Statistics and the resource person familiar with the relevant data bases	Department of Census and Statistics provide information through the Census as well as the different surveys. This information need to refine based on the requirements of the analysis. The variables for the analysis as well as data sources confined to the geographical locations need to be identify and process.
4	GIS expert (a resource person identified)	A resource person with the expertise in the GIS technologies needs to estimate the air quality in different geographical locations of the country. This could be done with the expertise beyond the consultant's capacity of handling the GIS as the health impact required.
5	Statistical analysis and data modelling experts (resource persons identified)	As the proposed methodology explained that the data need to analyze by using the advanced statistical methods and by using the data modelling software such as "Ben Map". They will be key resource for the project and they will be part of the project if the techniques are beyond the technical capacity of consultant.
6	Registrar General Department, Sri Lanka	Mortality data available in the Registrar General Department which are received from the Civil Registration System of the country is available. As

		a limitation, the latest data available is for the year 2013. However, attempts will be made to analyze the available information as described in the analysis plan.
7	ICD expert (a resource person identified)	Health data are classified based on the ICD (version 10). This classification gives the uniformity and will possible to compare with the other countries. However, data understanding and the processing need expertise in the field. There for data will be processed and streamlined based the expertise ICD classification.
8	Air Resource Management and National Ozone Unit	The staff of the Air Resource Management and National Ozone Unit was identified as a resource team for the project who will guide and evaluate the project direction.
9	Air Quality data providers	A series of air quality data providers were identified during the inception workshop. They are described by "consultant" working on the air quality and the data is essential for the health impact assessment.

Introduction: air quality and health

Air is a complex mixture of many components. Nitrogen and oxygen constitute approximately 99% of the mixture with the remainder being made up many components in trace quantities. Some of these trace quantities would be air pollutants. Following sections describe the important aspects of the air pollution pertaining to human health.

Definition of air pollution

The United States Environmental Protection Agency (USEPA) defines "air pollution" as "when the substances which have been emitted into the atmosphere exist throughout the atmosphere, over and above the natural physical diffusion and deposition functions, chemical elimination functions, and biological purification functions, are dispersed throughout the atmosphere and their volume exceeds natural conditions". An air pollutant can be defined as "a substance in the air that, in high enough concentrations, produces a detrimental environmental effect". USEPA further states that "these effects can be either health effects or welfare effects. A pollutant can affect the health of humans, as well as the health of plants and animals"(S Nandasena et al. 2012).

History of air pollution studies

Since prehistoric times when humans first moved to temperate climates, it was necessary to construct shelters and use fire inside the dwellings for cooking, warmth, and lighting. Indoor fires led to high levels of air pollution as evidenced by the soot found in prehistoric caves. Although thousands of years have passed, still half of the world's population and up to 90% of rural households in developing countries rely on unprocessed biomass fuels in the form of wood, dung and crop residues. The problem became worse with industrialization, which resulted in high outdoor emission sources, focusing attention on the need to control increased air pollution globally. A number of cities introduced smoke control ordinances around the turn of the 20th century, and by 1912, 23 of the largest 25 cities in the United States had ordinances principally aimed at visible smoke emanating from commercial establishments. Statistics on deaths resulting from air pollution in the 18th and 19th centuries and in the early part of the 20th century were collected in a few cities around the world. The famous "London's killer fog" was a reported extreme condition which lasted for five days in December 1952; it is estimated that that there were about 4000 deaths from the stagnant atmosphere of fog, smoke and SO_2. Epidemiological studies relating air pollution and health outcomes essentially began with this episode. Over the course of the 20th century with emerging scientific evidence, favorable attitudes and policies towards mitigating the adverse impacts of air pollution on health gradually developed. This resulted in many affluent cities being able to achieve cleaner air standards, at least to a certain extent.

Increased economic development has led to rapid and unplanned urbanization resulting in urban air pollution, which, in-turn, contributes to regional and global air pollution. Although air pollution is recognized as an emerging public health problem, most developing nations do not have data to assess its magnitude. A possible reason for this is that air pollution co-exists with other important public health problems, such as low immunization coverage, burden of communicable diseases, malnutrition, sanitation deficiencies, etc., which receive higher priority in low economic resource settings. This has delayed actions needed to adequately assess, evaluate and control air pollution in most urban regions and cities of the developing world. Only other hand, availability of air quality data is minimum. This limit the planning of epidemiological studies even if the health data is available(S Nandasena et al. 2012; McCracken et al. 2011; Balakrishnan Kalpana et al. 2014).

Burden of air pollution

Both indoor (i.e., households air pollution) and outdoor (i.e., ambient air pollution) air pollution have a considerable health impact and considered to one of the main burdens of diseases in environment. Ambient air pollution accounts for an estimated 4.2 million deaths per year due to stroke, heart disease, lung cancer and chronic respiratory diseases. It is estimated that about 91% of the world's population lives in places where air quality levels exceed WHO limits. Although the ambient air pollution affects both developed and developing countries; highest burden is in low- and middle-income countries (LMICs). Out of them greatest burden is reported from WHO Western Pacific and South-East Asia regions. Household air pollution accounts for 7.7% of global mortality. Nearly all of these deaths are in LMICs, where household air pollution is a leading cause of deaths from noncommunicable diseases. Figure 1 provide the major causes of deaths in Sri Lanka and its ranking as of year 2007 and 2017. The first four disease and the sixth and seventh leading killers are associated with the air pollution exposure based on the international literature. However, it should be emphasized that the air pollution exposure is not the only risk factor for these diseases, but air pollution exposure may act as a synergistic risk factor(Anon n.d.; Renzi et al. 2018; Eze et al. 2015).

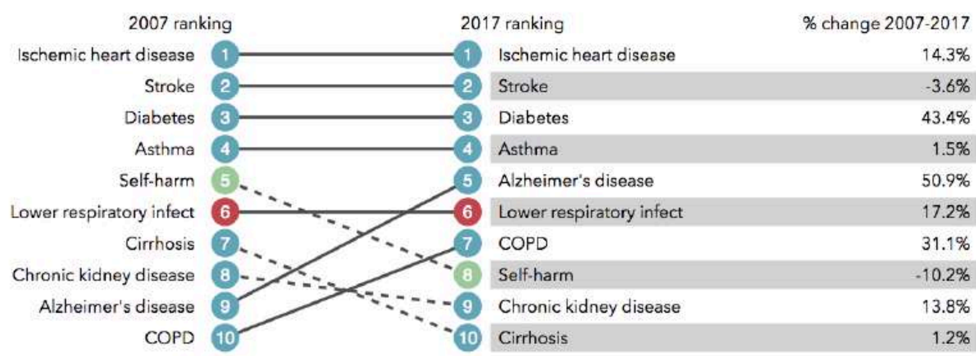


Figure 1: Major causes of deaths in Sri Lanka (Adapted from Institute of Health Metrix and Evaluation)

Types and sources of air pollutants

Type and sources of air pollutants determine the adverse health effects as well as duration of exposure. Perhaps, humans are exposed to complex mixtures of toxic indoor and outdoor pollutants generated and emitted by various sources. A source of air pollution may include any activity that causes pollutants to be emitted. These pollutants occur naturally or as a result of human activities. Natural sources of air pollutants (also known as **biogenic sources**) generally do not cause problems as compared to human generated air pollutants (**anthropogenic sources**). Sources of air pollution can be **mobile sources** or **stationary sources**. Mobile sources of air pollution include transportation vehicles such as automobiles. Stationary sources can be **point sources** which emit air pollutants from a fixed point such as from a smoke stack of a factory; an **area source** refers to a series of small sources that together can affect air quality in a region. A community of homes using wood stoves can be considered as an area source, although each individual home is contributing small amounts of various pollutants(S Nandasena et al. 2012).

The two basic physical forms of air pollutants are particulate matter (PM) and gases. PM includes small solid and liquid particles such as dust, smoke, sand, pollen, mist, and fly ash. Gases include substances such as ozone (O_3), carbon monoxide (CO), sulphur oxides (SO_x) and nitrogen oxides (NO_x). Although there are many air pollutants, the common and detrimental ones to human health (also known as "criteria pollutants") are PM, ground level O_3, CO, SO_x, NO_x and lead (Pb). The type of the pollutant may be different based on the source of the emission(S Nandasena et al. 2012).

PM is emitted directly from motor vehicles, power plants and various factories or formed in the atmosphere through reactions with gaseous emissions outdoors while fuel or tobacco combustion, cleaning and cooking emit them indoors. PM may consist of dust, polycyclic aromatic amines, heavy metals, pesticides and aerosols; these are considered to be the primary health damaging pollutants. NO_2 is a gaseous by-product of the combustion of fossil fuels in transportation and industrial applications such as waste incineration outdoors while cooking fuel combustion is the main indoor source. SO_2 is a gaseous by-product of the combustion of fossil fuels that contain sulfur. Usually SO_2 is emitted from solid fuels, liquid fuels (such as gasoline, diesel, and fuel oil) and natural gases. Coal combustion is a well-documented indoor source. Fuel or tobacco combustion is responsible for CO indoor emissions while motor vehicles and other combustion sources are responsible for outdoor emissions. O_3 is a gas formed in the atmosphere from the combination of NO_x and volatile organic compounds (VOC) under certain meteorological conditions(Bruce et al. 2000).

Variability of outdoor and indoor air pollutants

Outdoor air pollution, especially in urban environments, arises from a spectrum of sources and is unevenly dispersed. In general, higher concentrations are found near the source of pollution. As the vehicle fleet and road traffic increase, high outdoor air pollution can be noticed in urban areas where a higher proportion of the population live as compared to semi-urban or rural areas. Accumulation of industrial areas close to, or in, urban areas can lead to further deterioration of air quality.

Seasonality affects emission levels of most pollutant sources. Besides the emission levels, dispersion properties of the atmosphere vary between seasons, especially between normal and extreme conditions. Variability of emissions in time and space and variable dispersion conditions in the atmosphere give rise to different levels of pollution in a given environment.

The indoor exposures are a result of complex interactions between the structure, building systems, indoor source strength, ventilation rate, removal and deposition rate within the structure, indoor mixing and chemical reactions, furnishings, the outdoor environment, and practices and behaviours of habitants. Ventilation systems in buildings greatly impact on the removal rate of pollutants. When windows are open and the wind speed is moderate or high, indoor concentrations of air pollutants may be the same as that outdoors. High indoor pollutant concentrations can result in a closed indoor environment even with relatively modest emissions(Nandasena et al. 2013).

Exposure variability and vulnerability to air pollutants

Exposure to air pollutants can vary due to many factors such as area of residence, life style, occupation, cultural practices, socio economic status, age etc. Human exposure to air pollutants can occur both indoors and outdoors. Adults and children may spend more time indoors. Hence, a complete exposure assessment should include exposures of both indoors and outdoors. Personal exposure refers to the true integrated pollutant concentrations individuals are exposed to. When a person stays in one place, his/her personal exposure is determined by the air in that place. When he moves from one place to another his total exposure is determined by the weighted average of air quality measurements of all the places he visits(Sumal Nandasena et al. 2012).

Several population groups are more vulnerable to the effects of air pollutants, such as, those who are innately more susceptible to the exposure effects of air pollutants than others, those who become more susceptible as a result of environmental, social and personal behaviors, and those who are simply exposed to unusually large amounts of air pollutants. As the individual sensitivity to pollutants increases, the severity of the response will increase.

Groups that are more sensitive to air pollutants are the unborn and young children, elderly people, those with cardio-respiratory diseases, those who are exposed to other toxic materials that add to, or interact with, air pollutants, and the socio-economically deprived.

Children are more susceptible to the harmful effects of air pollution as compared to adults due to several reasons. Lung growth of children is guided through a complex chemical pathway and air pollutants are known to interfere with these chemical pathways. Thus, pollutants affect the developing and growing air ways and alveoli of children. The airway epithelium of growing children is more permeable to air pollutants and the lung defense system is not adequately evolved. Children have a differential ability to metabolize, detoxify, and excrete environmental agents thereby having the potential to result in more harm. Children engage in more physical activity than adults which leads to a higher intake of air as compared to body size. Further, children have a higher resting metabolic rate of oxygen consumption per unit body weight than adults as they have a larger surface per unit body weight and are growing rapidly. In addition, a high prevalence of asthma and other diseases, and high rates of acute respiratory infections increase the adverse effects of air pollutants in children.

Health effects of air pollutants

Harmful effects of air pollution begin even before birth. Some of these pollutants have been detected in the blood of pregnant mothers. Some of these pollutants enter the fetal circulation through the placenta and umbilical cord blood and adversely affect the health of the fetus. Humans inhale around 10,000 liters of air daily which comes in close contact with the lung surface creating the opportunity to directly affect the respiratory system and diffusion into the blood thereby having the potential to affect other systems as well. The spectrum of health effects due to air pollution varies from mild symptoms to premature mortality affecting different organ systems of all age groups.

The health effects depend on the type of the pollutant, its concentration, duration and frequency of exposure, and its associated toxicity. The frequency of occurrence of the health outcome is inversely related to its severity ranging from subclinical effects to premature mortality (Figure 1). Air pollutants generally do not exist in isolation, but in complex mixtures that create the potential for synergistic effects of the pollutants.

PM less than 10 microns in diameter (PM_{10}), and more importantly, those less than 2.5 microns ($PM_{2.5}$), are able to penetrate deep into the lungs and cause bronchial irritation, inflammation and increased reactivity in the respiratory system. They also reduce muco-ciliary clearance and macrophage responses. These effects may precipitate wheezing, an exacerbation of asthma, respiratory infections, chronic bronchitis and chronic obstructive pulmonary disease. Acute exposure to NO_2 increases bronchial reactivity while long term exposure increases susceptibility to bacterial and viral lung infections. Acute exposure to SO_2 increases bronchial reactivity that may present as wheezing, an exacerbation of asthma, exacerbation of COPD and cardiovascular diseases. CO binds with hemoglobin (Hb) to produce COHb which reduces oxygen delivery to key organs and the developing fetus resulting in low birth weight and in an increase in perinatal deaths. O_3 reduces lung functions, increases asthmatic attacks and increases the lung's reactions to other air pollutants and allergens. Elevated levels of lead can cause brain and other nervous system damage and adversely affect kidney function, blood chemistry, and digestion.

Respiratory health effects of air pollutants

Adverse respiratory health effects range from irritant effects and odors to increased mortality. Table 1 gives the possible adverse respiratory health effects that may be used to quantify the respiratory health effects due to air pollution(Nandasena et al. 2013).

Table 3:Adverse respiratory health effects due to air pollution

A.	Increased mortality
B.	Increased incidence of cancer
C.	Increased frequency of symptomatic asthmatic attacks
D.	Increased incidence of lower respiratory tract infections
E.	Increased exacerbation of disease in persons with chronic cardiopulmonary or other diseases that could be reflected in a variety of ways 1. Less able to cope with daily activities 2. Increased hospitalization, both frequency and duration 3. Increased emergency ward or physician visits 4. Increased pulmonary medication 5. Decreased pulmonary function
F.	Reduction of FEV_1 or FVC associated with clinical symptoms 1. Chronic reduction in FEV_1 or FVC associated with clinical symptoms 2. A significant increase in the number of persons with FEV_1 below normal limits 3. An increased rate of decline in pulmonary function (FEV_1) relative to the predicted value with increasing age in adults or failure of children to maintain their predicted FEV_1growth curve.
G.	Increased prevalence of wheezing
H.	Increased prevalence or incidence of chest tightness
I.	Increased prevalence or incidence of cough/phlegm production requiring medical attention
J.	Increased incidence of acute upper respiratory tract infections that interfere with normal activity

K.	Acute upper respiratory tract infections that do not interfere with normal activity
L.	Eye, nose, and throat irritation that may interfere with normal activity
M.	Odours

Adapted from the American Thoracic Society(Morici et al. 2019).

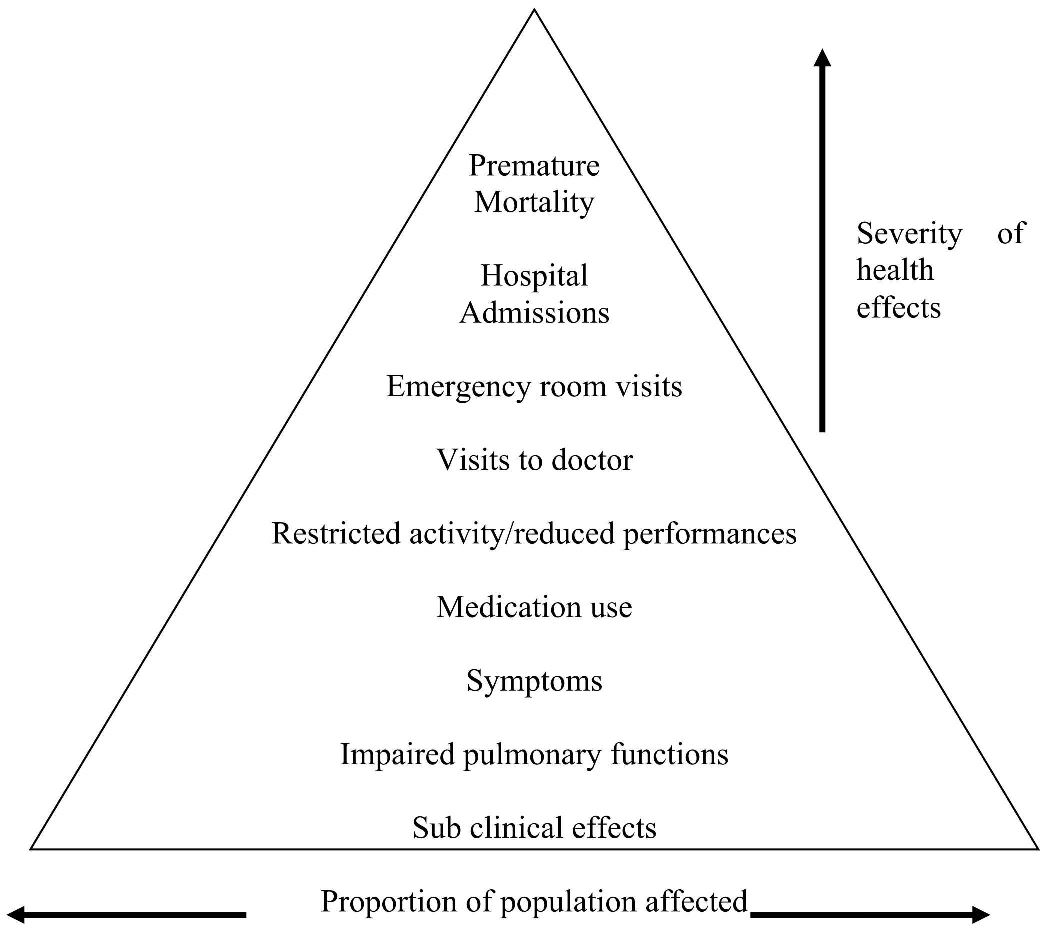


Figure 2: Air pollution - health effects pyramid (Adapted from the WHO report on quantification of the health effects due to exposure to air pollution, (WHO 2000))

One of the strongest predictors of mortality in adults is lung functions. Factors that affect lung functions in adults are strongly impacted by the growth and development of lung functions in childhood. Studies of lung functions in children suggest that those who were living in areas with high levels of air pollution have poorer lung functions and long-term exposure results in poor lung growth. A reduction in air pollution leads to an improvement in lung function and lung growth. Air pollution may only account for a small proportion of the reduction in lung function, but, even that, may be clinically important in susceptible persons.

Non-respiratory health effects

A range of non-respiratory health effects are resulted from air pollution. Some of the international studies on different settings and different air pollutants are given below.

Most epidemiological studies have shown that indoor and outdoor air pollution result in low birth weight (LBW) as well still births. (Shah et al. 2011). Brauer et al. followed up a large cohort of 70,249 live births since pregnancy measuring the air pollutant exposure via GIS based methods. Residents within 50m of highways had a 26% increased risk of small for gestational age birth weights (95% CI: 1.07-1.49) and 11% (95% CI:1.01-1.23) increased risk of LBW(Brauer et al. 2008).

Several cardiovascular conditions are associated with both indoor and outdoor air pollution. Lin et al. measured indoor $PM_{2.5}$, PM_{10} and NO_2 in households of young university students (n=40) in Taipei and showed a significant association between high PM levels and blood pressure (both systolic and diastolic) and heart rate. They recommended reducing the indoor PM levels by closing windows of the houses in heavily polluted areas where the PM source can be from the outdoor environment.

Yorifuji et al. studied NO_2 exposure of a cohort of 14,001 older residents in Shizuoka, Japan followed up from 2000 to 2006. Traffic related exposure of NO_2 levels were modeled for each individual using the land regression model. The adjusted ischemic heart disease mortality risk was 1.27 (95%CI 1.02- 1.58) times higher for a 10 $\mu g/m^3$ increase of NO_2. Link et al. reviewed the available evidence for the cardiovascular effects of air pollution and concluded that there is a strong relationship between increased levels of air pollutants and acute triggering of myocardial infarctions and arrhythmias. They recommended that patients with underlying risk be vigilant about the local air quality index and follow the recommendations minimizing the air pollutant exposures.

Health data sources in Sri Lanka

Prior to the data analysis, each source of health data was in-depth reviewed. Following description state the nature of the data with strengths and weakness of the data set. This will be important to consider in planning the data analysis as well as assumptions to made in the data analysis.

Electronic Indoor Morbidity and Mortality Register (eIMMR)

eIMMR is key data source available from the government health sector. Following strengths and weaknesses are available in the data base.

Strengths

The information is available in the electronic format

Patient information is available with the categorization according to the International Classification of Disease – Version 10. Therefor findings give the scientific classification as well as they can be compared with the other countries.

Weaknesses

(1) The data base includes only the indoor morbidity and mortality data. Thus, the patients attended to the outpatient departments (OPD) is not available with the data base. As a weakness of the national health system, only the number of patients admitting to the hospital are available

(2) As another limitation of Sri Lankan health system, the patients can attend to any hospital they prefer. This make the confusion of bypassing the hospital which is the closest to the patients.

(3) eIMMR cover only about 90% of government hospitals. That means 10% of government hospitals does not include in the eIMMR. Almost all private hospitals are not covered by the eIMMR. However, it is estimated that only 10%-20% of indoor care is provided by the private hospitals in Sri Lanka.

(4) Data will have hospitals deaths only. Usually deaths may be happened with in hospitals as well as outside the hospitals. However, the deaths happen in the outside of hospital are not available with this data base. It is estimated that only the 40-60% of all deaths are happen with in the hospitals.

Mortality data from the Registrar General Department

Based on the death registration by the "death registrars" of the country, registrar general department develop the data base on death and causes of deaths in Sri Lanka. However, there are strengths and weaknesses in the data set as given below.

Strengths

At least 95% of the deaths in Sri Lanka are registered under the "death registrars" of the country". Therefore, it is a near normal complete data set.

Weakness

(1) The latest data set available is for the year 2013

(2) Sri Lankan death registrars do not medically qualified in all the occasions thus they could not accurately label the cause of death. This give rise to the possibility of misclassification of deaths. Therefore, the data set is much efficient in calculation of total death count in an area, there are limitations in the calculation of the cause of deaths.

Data from the other national surveys

The national surveys conducted by the Department of Census and Statistics are considered to be scientifically valid and robust. Data from the following surveys are important.

1) Census 2012
2) Demographic and Health Survey 2016
3) Household Income and Expenditure Survey 2016
4) National Survey on Self-Reported Health - 2014

Following strengths and weakness are in these surveys in terms of health impact assessments.

Strengths

1. Data are nationally and district wise representative
2. Census data are population based and some of the important variables such as use of primary cooking fuel is available.

Weakness

1. Other than the Census 2012, other data is based on the representative samples thus cannot be taken for all the geographical locations in the country.
2. Health conditions are not classified ICD-10 classification.

Health sector in Sri Lanka

Health systems in Sri Lanka include the allopathic medicine, Ayurveda medicine, traditional medicine, etc. Allopathic medical care is dominating the health services in Sri Lanka. Medical treatments are organized as inward and outpatient care. While the patients having minor elements/diseases are treated as out patients at the out patients departments (OPD) and the primary medical care units (PMCU), patients having serious illnesses that need inward care will be admitted to the hospitals with residential care. Both the inward and the outpatient care in allopathic medicine is provided by the government as well as the private sector.

Public (e.g., government) vs. private allopathic care

Outpatient care is split almost evenly between the public (i.e., government) and private sectors, with the private sector providing marginally more services (World Bank, 2014). In the case of inpatient care, this is different, whereas private provision is small at about five to ten percent, with the remainder being provided by the public sector. The role played by nongovernment organizations (NGOs) in providing health care is marginal, except for their important role in family planning (World Bank, 2014). Figure 3 provide the schematic diagram of the allopathic health sector in Sri Lanka.

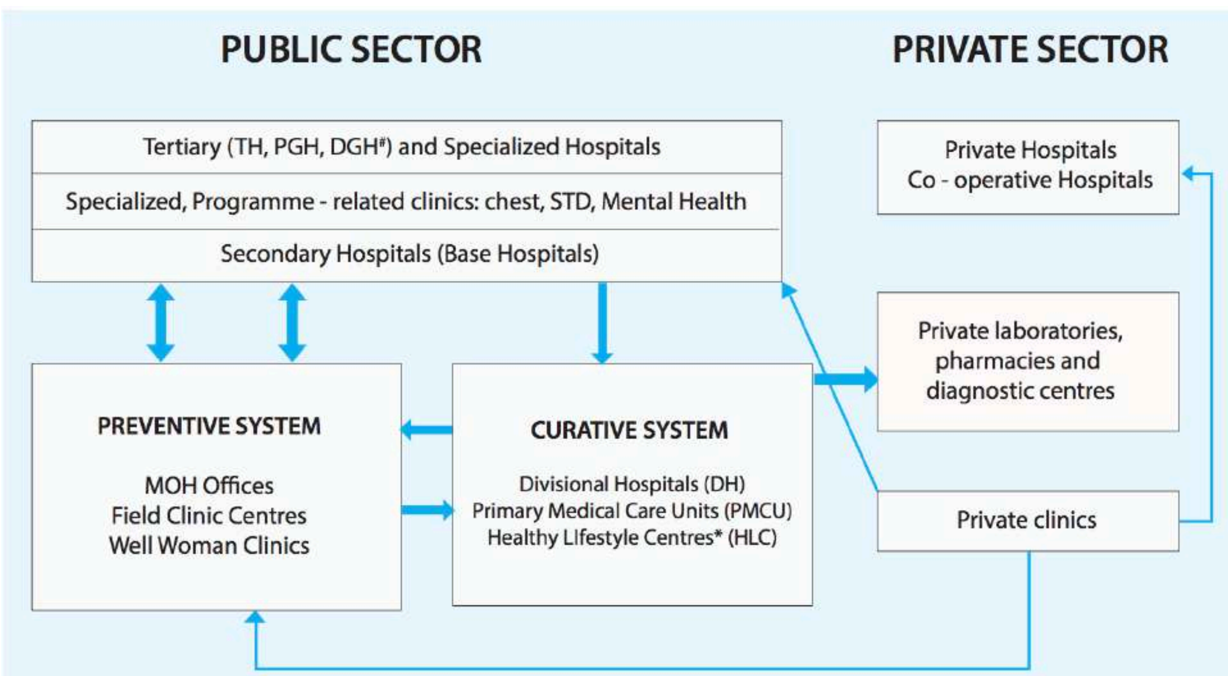


Figure 3: Sri Lankan allopathic health care delivery system (Adopted from Essential Service package of Sri Lanka, 2019)

According to data provided by the Central Bank of Sri Lanka, the public sector accounted for 73% of the hospitals and 93% of the available bed capacity in Sri Lanka, while handling over 90% of the total patient admissions and outpatient visits to hospitals as of end 2014 (Institute of Health Policy, 2015).

The private sector consisted mainly of a few leading hospital chains and a large number of small regional players. The capacity concentration was moderate, with the top five hospitals accounting for approximately 45%.

It is estimated that a total of 125 institutions, with approximately 4,200 beds, operated as private hospitals in Sri Lanka in 2011. These hospitals delivered approximately 266,000 inpatient admissions and 4.7 million outpatient visits per year (The number of admissions per private hospital bed per year increased from 50 (1990) to 55 (2009). This was a smaller increase compared to the government hospitals, where admissions per hospital bed increased from around 50 in 1990 to nearly 80 in 2009 (Institute of Health Policy, 2015).

Table 4: Number of admissions and outpatient visits for public and private hospitals: Number of admissions and outpatient visits for public and private hospitals, 1990–2009

	Number of Admissions		Number of Outpatients		Share of Admissions (%)		Share of Outpatients (%)	
Year	Public	Private	Public	Private	Public	Private	Public	Private
1990	2,459,000	100,200	28,401,000	1,115,000	96.1	3.9	96.2	3.8
1991	2,629,000	104,700	28,635,000	1,146,000	96.2	3.8	96.2	3.8
1992	3,024,000	111,200	36,827,000	1,322,000	96.5	3.5	96.5	3.5
1993	3,174,000	121,400	37,384,000	1,501,000	96.3	3.7	96.1	3.9
1994	3,204,000	124,000	34,983,000	1,630,000	96.3	3.7	95.5	4.5
1995	2,953,000	129,800	32,106,000	1,758,000	95.8	4.2	94.8	5.2
1996	3,339,000	140,800	37,411,000	1,871,000	96.0	4.0	95.2	4.8
1997	3,454,000	137,800	39,468,000	1,979,000	96.2	3.8	95.2	4.8
1998	3,791,000	141,000	41,071,000	2,248,000	96.4	3.6	94.8	5.2
1999	3,826,000	145,600	41,305,000	2,667,000	96.3	3.7	93.9	6.1
2000	4,015,000	145,100	43,329,000	2,997,000	96.5	3.5	93.5	6.5
2001	4,092,000	147,900	43,434,000	3,289,000	96.5	3.5	93.0	7.0
2002	4,032,000	160,500	45,620,000	3,544,000	96.2	3.8	92.8	7.2
2003	3,993,000	174,400	43,632,000	3,702,000	95.8	4.2	92.2	7.8
2004	4,009,000	183,600	41,167,000	3,604,000	95.6	4.4	92.0	8.0
2005	4,345,000	179,200	42,483,000	3,490,000	96.0	4.0	92.4	7.6
2006	4,463,000	197,800	41,430,000	3,482,000	95.8	4.2	92.2	7.8
2007	4,609,000	203,100	43,074,000	3,473,000	95.8	4.2	92.5	7.5
2008	4,898,000	220,400	45,382,000	3,856,000	95.7	4.3	92.2	7.8
2009	5,474,000	228,300	48,782,000	3,835,000	96.0	4.0	92.7	7.3

Source: IHP PHNHs database 2012, Annual Health Bulletins, Medical Statistics Unit MoH and IHP Public Facility database 2011

In the private sector, total inpatient admissions increased from approximately 100,000 to 266,000, whilst outpatient numbers increased around four-fold from 1.1 million to 4.7 million during 1990–

2011. This compares with 5.5 million admissions and 48.8 million outpatient visits at governmental institutions in 2009 (Institute of Health Policy, 2015). Further, out of the total inpatient admissions in the country, one in 25 admissions were in the private sector (4%) and every one in 14 outpatient visits to a hospital were to a private sector hospital (8%) in 2009. Private hospital beds represent6% of the total hospital beds in the country in 2009.

The share of private sector admissions among all hospital admissions in the country has remained at around 4% from 1990 to 2009 (Figure 1). The share of private sector outpatient visits among all hospital outpatient visits has increased from 4% in 1990 to 7% in 2009 (Figure 2).
The number of admissions per private hospital bed per year increased from 50 (1990) to 55 (2009). This was a smaller increase compared to the government hospitals, where admissions per hospital bed increased from around 50 in 1990 to nearly 80 in 2009.

In the private sector, few of the hospitals (e.g., Dr Neville Fernando Teaching Hospital (NFTH), Asiri Hospital Holdings PLC (Asiri), Nawalok Hospitals PLC (Nawaloka), Durdans Hospitals (Durdans) and The Lanka Hospitals) contributed immensely in terms of indoor and out patients care in allopathic medicine. Perhaps these set of five hospitals accounted for ~45% of the private-sector bed capacity at the end of 2014. The top five are concentrated mainly in Colombo and its suburbs, but some have expanded their reach to districts with strong growth potential such as Gampaha, Matara and Kandy.

Methodology

Based on the suggestions made by the experts about the potential data sources in Sri Lanka and the extensive literature search, following methodology was developed for the directions of the health impact assessment. Further the methodology was based on the stated objectives of the "Terms of Reference" and scope of the analysis based the agreement of Ministry of Environment and the Mahaweli Development with the United Nations Environmental Programme. Following key sources of health data and their strengths and the weaknesses were also identified which is important to make assumptions during the analysis and develop recommendations.

Health outcomes for data analysis

Considering the strength and weakness of the existing health data sources data analysis plan was developed. One of the first step in the data analysis plan is to identify the possible health outcomes to consider in the analysis. With the rigorous literature search including the meta-analysis and the global burden of the disease calculation related to the impact of air pollution, the health outcomes which are associated with the air pollution was identified based on the ICD-10 classification. There are

- Diseases of the respiratory system (diseases such as asthma)
- Diseases of the circulatory system (diseases such as ischemic heart diseases)
- Endocrine, nutritional and metabolic diseases (disease such as diabetes mellitus)
- Diseases of the eye and adnexa (eye diseases such as cataracts)
- Neoplasams (i.e., cancers)

Out of key three sources of health information explained above, eIMMR was considered as the most promising and feasible data source for further analysis. The analysis methods for the data base is further explain below.

Analysis method of eIMMR data base

Initially the available variables of the eIMMR was studied and the important variables were identified. Table 2 gives the important variables in the eIMMR data base for the analysis.

The important variables in the eIMMR for the analysis were hospital of admission, district, admission date, age, sex, ICD code and discharge mode. Those variables of the eIMMR data

Table 5:Variables to be obtained from the eIMMR data base

No	Variable Name
1	Hospital
2	District
3	Admission date
4	Age
5	Sex
6	ICD Code
7	Discharge Mode

base was formally obtained from the Medical Statistics Unit of Ministry of Health, Sri Lanka (Annexure 4 – data request letter from Ministry of Health). Figure 1 shows the sample data sheet used for analysis.

ICD (International Classification of Diseases)

The purpose of the ICD is to permit systematic recording, analysis, interpretation and comparison of mortality and morbidity data collected in different countries or areas and at different times. The ICD is used to translate diagnoses of diseases and other health problems from words into an alphanumeric code, which permits easy storage, retrieval and analysis of the data. In practice, the ICD has become the international standard diagnostic classification for all general epidemiological and many health-management purposes. These include analysis of the general health situation of population groups and monitoring of the incidence and prevalence of diseases and other health problems in relation to other variables, such as the characteristics and circumstances of the individuals affected.

district_name	hospital_name	Age	Sex	Mode	AdmissionDate	ICD_code	IMMR_code
Colombo	Hospital x	9	Male	live	3-Jan-17	E10.1	090A
Colombo	Hospital x	6.8333	Male	live	11-Jan-17	E10.1	090A
Colombo	Hospital x	13	Female	live	21-Jan-17	E10.1	090A
Colombo	Hospital x	6	Female	live	23-Jan-17	E10.1	090A
Colombo	Hospital x	6	Female	live	23-Jan-17	E10.1	090A
Colombo	Hospital x	11	Female	live	7-Feb-17	E10.1	090A
Colombo	Hospital x	12	Male	live	6-Mar-17	E10.1	090A
Colombo	Hospital x	9.25	Male	live	3-Mar-17	E10.1	090A
Colombo	Hospital x	10	Female	live	5-Mar-17	E10.1	090A
Colombo	Hospital x	2.3333	Male	live	5-Mar-17	E10.1	090A
Colombo	Hospital x	11	Female	live	16-Mar-17	E10.1	090A
Colombo	Hospital x	8	Male	live	26-Mar-17	E10.1	090A
Colombo	Hospital x	13	Female	live	22-Apr-17	E10.1	090A
Colombo	Hospital x	13	Male	live	2-May-17	E10.1	090A
Colombo	Hospital x	10	Male	live	4-May-17	E10.1	090A
Colombo	Hospital x	14	Female	live	1-Jun-17	E10.1	090A
Colombo	Hospital x	12	Female	live	27-Jun-17	E10.1	090A
Colombo	Hospital x	8	Male	live	1-Jul-17	E10.1	090A
Colombo	Hospital x	10	Female	live	17-Jul-17	E10.1	090A
Colombo	Hospital x	12	Female	live	28-Jul-17	E10.1	090A
Colombo	Hospital x	2	Female	live	29-Jul-17	E10.1	090A
Colombo	Hospital x	9	Male	live	31-Jul-17	E10.1	090A
Colombo	Hospital x	2	Female	live	7-Aug-17	E10.1	090A
Colombo	Hospital x	10	Female	live	26-Aug-17	E10.1	090A

Figure 3: Sample sheet of the data for selected variables (hospital name is deleted due to ethical reasons)

As the shown in table 2, "hospital" variable is important to approximately localise the hospital and assess the association with the air quality levels in terms of geographical context. Similarly, district would be important for the analysis. Admission date will give be important to the time series analysis since the air quality would change over the time. "Age" and "sex" are important to categorise based on the age and sex of the patients. Finally, ICD code would be important to assess association of different health outcomes with the air quality levels. The table 3 gives the necessary ICD codes (i.e., health outcomes) to assess the association of air quality.

<u>ICD codes of the health outcomes</u>

ICD coding is important for the accurate defining of the health outcomes. Therefore, ICD coding of each health outcome and their subcategories were identified with referring to World Health Organization ICD -10 documentations. Table 3 gives the ICD 10 codes to be considered in the analysis. These ICD codes were requested from the Medical Statistics Unit, Ministry of Health for analysis purpose.

Table 6: The ICD codes to be used for the data analysis

	Disease Category	ICD 10 code
1	**Diseases of the respiratory system**	J00-J06 Acute upper respiratory infections J09-J18 Influenza and pneumonia J20-J22 Other acute lower respiratory infections J30-J39 Other diseases of upper respiratory tract

		J40-J47 Chronic lower respiratory diseases J60-J70 Lung diseases due to external agents J80-J84 Other respiratory diseases principally affecting the interstitium J85-J86 Suppurative and necrotic conditions of lower respiratory tract J90-J94 Other diseases of pleura J95-J99 Other diseases of the respiratory system
2	Diseases of the circulatory system	I10-I15Hypertensive diseases I20-I25Ischaemic heart diseases I26-I28 Pulmonary heart disease and diseases of pulmonary circulation I30-I52 Other forms of heart disease I60-I69Cerebrovascular diseases
3	Endocrine, nutritional and metabolic diseases	E10-E14Diabetes mellitus
4	Diseases of the eye and adnexa	H25-H28 Disorders of lens
5	Neoplasms	C30-C39Malignant neoplasms of respiratory and intrathoracic organs

Statistical analysis

Initially data base was filtered for different type of health outcomes, specifically for respiratory diseases and the cardiovascular diseases. During the data analysis, “transfers” from one hospital to the another were removed to minimize the overlapping. This reduced the possible misclassification bias. Data analysis was conducted for morbidity and mortality separately. In the case of mortality whole cause mortality of five disease categories were used. Since the air quality data was available only for nine cities, as shown in the table 7, the data analysis was limited to the hospitals in these nine cities in the eight districts.

Table 7: Passive sampler air quality level (Monthly average value for SO_2 and NO_2) available cities and period

	City	Air quality data
1	Colombo*	2002-2018 (lacking 2010-2012)
2	Kandy*	2014 – 2018
3	Gampaha	2012 – 2018
4	Kalutara	2012- 2018
5	Rathnapura	2012- 2018
6	Galle	2012 – 2018
7	Kurunegala	2015 – 2018
8	Anuradhapura	2016 - 2018
9	Horana	2016 - 2018

* $PM_{2.5}$ for year 2018

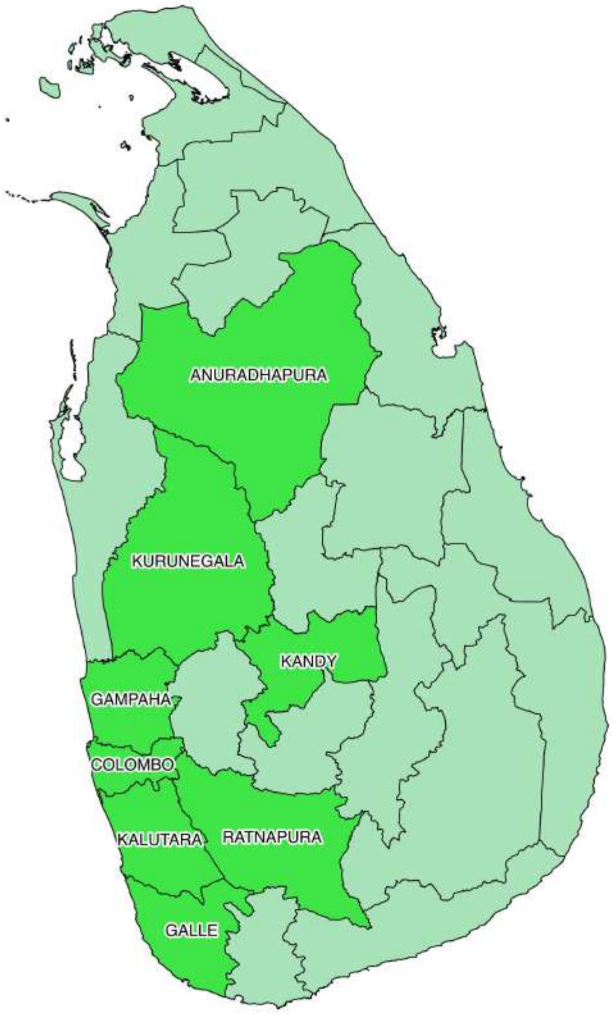


Figure 4: Districts selected for the analysis based on the availability of air quality data (Dark green colour)

Figure 4 provides the distribution of selected districts. It could be noticed that the selected districts are distributed across the country and also included the all populated and urbanized districts.

Table 5: The dummy table to fill by obtaining/ calculation of the statistics for different variables.

City	Air quality concentration	Number of deaths	Population under care	Morality rate

Then the standardized mortality rate of each area was correlated with the air pollutant concentration. This analysis was completed by Statistical Package of Social Sciences version 20 (SPSS – 20).

Mortality data from the registrar general department

Data of the registered deaths were obtained from the registrar general department (RGD). The data of the year 2017 has not categorized so far based on the age. Therefor the crude death rate was calculated.

Data from the other national surveys

There is important information received from national surveys (stated above) with geographical representativeness. Population estimation was obtained from this data.

As an example, exposure to indoor air pollution can be shown. As a proxy for this variable for indoor air pollution, propotion of population using the wood for the indoor air pollution can be shown.

Demographic and Health Survey - 2016; Household Income and Expenditure Survey - 2016 and National Survey on Self-Reported Health -2014 are different surveys other than the census data available but limited to a nationally representative, since it is based on a sample of entire population. However, these surveys give the district level estimates for several health outcomes such as for acute and chronic respiratory conditions and the self-reported diabetes and other non-communicable disease conditions. These conditions will be cross tabulated with the available air quality levels at district and city level.

Results

The data analysis was conducted as three components and based on different sources of data. The three components as follow (Figure 5).

1. **Component 1:** Association of data from the Electronic Indoor Morbidity and Mortality Register and passive sampler data from the National Building Research Organization
2. **Component 2:** Association of data from Registrar General Department and passive sampler data from the NBRO
3. **Component 3:** Association of data from the Electronic Indoor Morbidity and Mortality Register and Continuous data from the Central Environmental Authority (CEA)

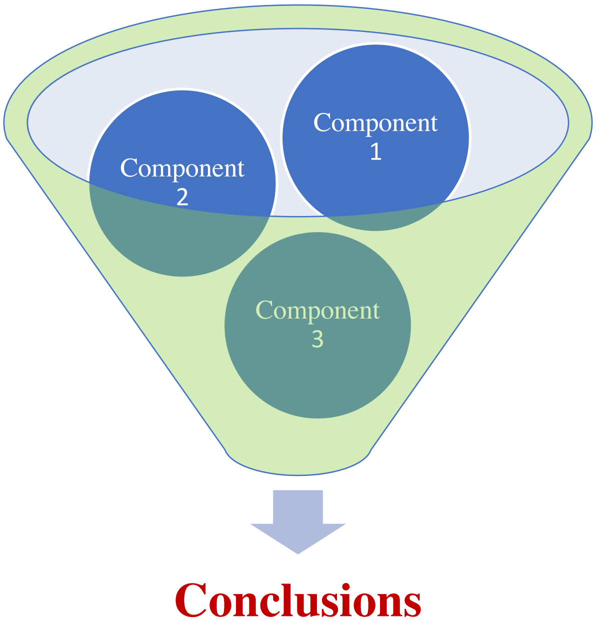


Figure 5: Components of the study

<u>Component 1: Association of data from the Electronic Indoor Morbidity and Mortality Register and passive sampler data from the National Building Research Organization</u>

It was important to describe the nature of the eIMMR data base, passive sampler data from the NBRO. Following sections, initially describe the descriptive statistics of each data base and then assess the association.

Descriptive Statistics of the Electronic Indoor Morbidity and Mortality Register

All the admissions of the government hospitals. There were 556401 hospital admissions in the selected eight districts for the year 2017. Out of them 48.9% were female and the rest were male. Majority (41.6%) of the patients were over 60 years of age. Table 7 gives the related information.

Table 8: Gender distribution of government hospital admissions in the selected districts

Gender	Frequency	Percent
Female	272147	48.9
Male	284254	51.1
Age		
18 or less	121686	21.9
More than 18 to 60	202225	36.3
More than 60	232490	41.8
Total	**556401**	**100.0**

Table 8 provide the admissions of the government hospitals in the selected nine districts. Majority of the admissions were reported from the Colombo district and the lowest reported from Kalutara district.

Table 9: District distribution of total admissions of government hospitals in year 2017 in Sri Lanka

District	Frequency	Percent
Anuradhapura	55649	10.0
Colombo	94388	17.0
Galle	52324	9.4
Gampaha	86249	15.5
Kalutara	51940	9.3
Kandy	83504	15.0
Kurunegala	77147	13.9
Ratnapura	55200	9.9
Total	**556401**	**100.0**

Admissions of the patients for selected disease categories are provided in the table 10. Out of the selected categories, Acute lower respiratory tract infections were the highest percentage (n = 53049, 9.5%) while influenza and pneumonia were 2.7% (n = 15262) and chronic lower reparatory infections were 18.5% (n = 102944).

Table 10: Disease categories of admitted patients

Disease category	Frequency	Percent
Acute upper respiratory infections	53049	9.5
Influenza and pneumonia	15262	2.7
Other acute lower respiratory infections	115993	20.8
Other diseases of upper respiratory tract	10859	2.0
Chronic lower respiratory diseases	102944	18.5
Lung diseases due to external agents	1494	0.3
Other respiratory diseases principally affecting the interstitium	776	0.1
Suppurative and necrotic conditions of lower respiratory tract	646	0.1
Other diseases of pleura	1411	0.3
Other diseases of the respiratory system	10128	1.8

Hypertensive diseases	43560	7.8
Ischemic heart diseases	60929	11.0
Cerebrovascular diseases	29676	5.3
Diabetes mellitus	40916	7.4
Disorders of lens	41105	7.4
Malignant neoplasms of respiratory and intrathoracic organs	8307	1.5
Pulmonary heart disease and diseases of pulmonary circulation	2728	0.5
Other forms of heart disease	16618	3.0
Total	**556401**	**100.0**

Mode of the discharge of the patients are provided in the table 11. Majority of the patients (90.3%) were discharged live, while 7.1% transferred to another hospital. There were 15535 (2.6%) deaths were reported from the selected disease conditions.

Table 11: Discharge mode of the patients

Discharge mode	Frequency	Percent
Death of the patient	14704	2.6
Left against medical advice	75	0.0
Live discharge	502281	90.3
Patient missing	27	0.0
Transfer to another hospital	39314	7.1
Total	**556401**	**100.0**

Table 12: Cross-tabulation of selected diseases and the discharge mode

Disease category		Live discharge	Transfers	Deaths	LAMA	Missing	Total
Acute upper respiratory infections	n	51023	2015	6	2	3	53049
	%	10.2%	5.1%	0.0%	2.7%	11.1%	9.5%
Influenza and pneumonia	n	12075	855	2328	4	0	15262
	%	2.4%	2.2%	15.8%	5.3%	0.0%	2.7%
Other acute lower respiratory infections	n	109910	5773	307	1	2	115993
	%	21.9%	14.7%	2.1%	1.3%	7.4%	20.8%
Other diseases of upper respiratory tract	n	10622	230	7	0	0	10859
	%	2.1%	0.6%	0.0%	0.0%	0.0%	2.0%
Chronic lower respiratory diseases	n	97055	4694	1182	9	4	102944
	%	19.3%	11.9%	8.0%	12.0%	14.8%	18.5%
Lung diseases due to external agents	n	646	43	805	0	0	1494
	%	0.1%	0.1%	5.5%	0.0%	0.0%	0.3%
Other respiratory diseases principally affecting the interstitium	n	631	24	120	1	0	776
	%	0.1%	0.1%	0.8%	1.3%	0.0%	0.1%
Suppurative and necrotic conditions of lower respiratory tract	n	590	28	28	0	0	646
	%	0.1%	0.1%	0.2%	0.0%	0.0%	0.1%
Other diseases of pleura	n	1265	115	30	1	0	1411
	%	0.3%	0.3%	0.2%	1.3%	0.0%	0.3%
Other diseases of the respiratory system	n	9554	432	140	2	0	10128
	%	1.9%	1.1%	1.0%	2.7%	0.0%	1.8%
Hypertensive diseases	n	39803	3350	393	9	5	43560
	%	7.9%	8.5%	2.7%	12.0%	18.5%	7.8%
Ischaemic heart diseases	n	45621	11424	3871	9	4	60929
	%	9.1%	29.1%	26.3%	12.0%	14.8%	11.0%
Cerebrovascular diseases	n	21388	6005	2270	12	1	29676
	%	4.3%	15.3%	15.4%	16.0%	3.7%	5.3%
Diabetes mellitus	n	37932	2345	626	7	6	40916
	%	7.6%	6.0%	4.3%	9.3%	22.2%	7.4%
Disorders of lens	n	41046	55	0	4	0	41105
	%	8.2%	0.1%	0.0%	5.3%	0.0%	7.4%
Malignant neoplasms of respiratory and intrathoracic organs	n	7619	140	536	10	2	8307
	%	1.5%	0.4%	3.6%	13.3%	7.4%	1.5%
Pulmonary heart disease and diseases of pulmonary circulation	n	2524	78	126	0	0	2728
	%	0.5%	0.2%	0.9%	0.0%	0.0%	0.5%
Other forms of heart disease	n	12977	1708	1929	4	0	16618
	%	2.6%	4.3%	13.1%	5.3%	0.0%	3.0%
Total	n	502281	39314	14704	75	27	556401
	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 12 provide the information about the selected disease categories and the discharge mode. More than one fourth of the deaths are reported from the ischemic heart diseases. Almost one fourth of the patients are discharged live those who had the "Other acute lower respiratory infections".

<u>Adjustment for total population seek medical care from government hospitals in the year 2017 in the Colombo district</u>

Due to the urbanization of the population, and extensive availability of private health sector in the Western Province, adjustments were made for the total population under care as follow. Based on the detailed statistical analysis under the section "Public (e.g., government) vs. private allopathic care, it is estimate that the 10% of the population of District of Colombo would rely on the private health sector for the hospital admissions. Thus, the estimated population of the Colombo district was adjusted accordingly as shown in the table 13. However, this was taken as 5% for Gampaha and Kalutara districts while considered as negligible for other districts. Estimated population for each district is provided in annexure 3.

Table 13: Population adjustment for selected districts

	District	Original Population	**Adjustment percentage**	Estimated population
1	Colombo	**2419000**	**10%**	**2177100**
2	Gampaha	**2391000**	**5%**	**2151900**
3	Kalutara	**1271000**	**5%**	**1143900**

<u>Predictions of deaths and admissions related to air pollution related diseases in NHSL in the year 2017</u>

As a limitation of the electronic data base, data of the National Hospital Sri Lanka (NHSL) was not available. Since the admissions to the NHSL is sizable and need to be considered, estimate was done based on the other hospitals located in Colombo as below. It is assumed the propotion of patients admitted for diseases selected for the study were similar for below hospitals.

- Colombo South Teaching Hospital, Kalubowila
- East Colombo Base Hospital, Angoda
- Sri Jayawardenepura Teaching Hospital

However, several other hospitals located in the district of Colombo were not taken in this estimation due to several reasons as shown in table 14.

Table 14: Hospitals in Colombo which are not considered in the estimation of admissions in National Hospital in Sri Lanka

	Hospital Name	Reason
1	Apeksha Hospital, Maharagama	Specialized hospital for cancer care
2	Castle Street Hospital for Women	Specialized hospital for maternity care
3	De Soysa Hospital for Women	Specialized hospital for maternity care
4	Lady Ridgeway	Specialized hospital for child care
5	National Dental Hospital	Specialized hospital for dental care
6	National Eye Hospital	Specialized hospital for eye care
7	National Institute for Mental Health, Angoda	Specialized hospital for mental care
8	Wetara Divisional Hospital	Divisional hospital without specialized care
9	Moratuwa Divisional Hospital	Divisional hospital without specialized care
10	Nawagamuwa Divisional Hospital	Divisional hospital without specialized care
11	Padukka Divisional Hospital	Divisional hospital without specialized care
12	Piliyandala Divisional Hospital	Divisional hospital without specialized care
13	Thalangama Divisional Hospital	Divisional hospital without specialized care
14	Athurugiriya Divisional Hospital	Divisional hospital without specialized care
15	Colombo Central, Maligawatta	Divisional hospital without specialized care
16	Kosgama Divisional Hospital	Divisional hospital without specialized care
17	Avissawella Base Hospital	Located in periphery of the Colombo district. Patient drain area is mostly with the low exposure
18	Homagama Base Hospital	Located in periphery of the Colombo district. Patient drain area is mostly with the low exposure

As shown in the table 15, based on the total admissions, and admissions and deaths for the selected diseases estimated propotion of admissions and deaths for the air pollution related disease were calculated. Based the estimation, out of the total deaths in the selected hospital, 57.3% could be attributed for the air pollution related diseases. Similarly, out of the total admissions in the selected hospital, 14.3% could be attributed for the air pollution related diseases.

Table 15: Average admissions and deaths in the District of Colombo

	Colombo South Teaching Hospital, Kalubowila	East Colombo Base Hospital, Angoda	Sri Jayawardenepura Teaching Hospital	Total of three hospitals
Total Admissions	134804	25120	70648	230572

Admissions on air pollution related diseases	17869	3403	11802	33074
Live Discharge	133034	24874	69708	227616
Total deaths	1770	246	940	2956
Live Discharge on air pollution related diseases	16572	3265	11305	31142
Deaths related to air pollution related diseases	1090	106	497	1693
% of admissions of air pollution related diseases	13.3	13.5	16.7	**14.3**
% of deaths of air pollution related diseases	61.6	43.1	52.9	**57.3**

Based on estimated propotion of the admissions and deaths attributed to air pollution related diseases, out of the total number of admissions of the NHSL, predictions were made for the admissions and deaths as shown in table 16. Based on the predictions, there could be 37569 admissions and 3129 deaths based on diseases considered for this analysis.

Table 16: Estimation of admissions and deaths of NHSL based on the predictions of Colombo District

Total Admissions	Live Discharge	Total deaths	Predicted admission due to air pollution related diseases (%)	Predicted deaths due to air pollution related diseases (%)	Estimated admission due to air pollution related diseases	Estimated Deaths related to air pollution related diseases
261907	256443	5464	14.34	57.27	37569	3129

Comparison of deaths due to the air pollution related diseases and the NO_2 and SO_2 concentrations

Table 17 provides the NO_2 and SO_2 concentrations and the death rate. Death rate were calculated based on the adjusted population and the total estimated deaths of each district for the air pollution associated diseases. Death rate was calculated for 100,000 population. Highest death rate and the highest SO_2 concentration was reported from Colombo district.

Table 17: Comparison of death rate and air quality levels in selected districts

	Deaths	Population	Adjusted population*	Total estimated deaths**	Crude Death rate***	NO_2	SO_2
Anuradhapura	1261	918000	918000	1261	1.374	23	39
Colombo	2717	2419000	2177100	5846	2.685	39	51
Galle	1765	1113000	1113000	1765	1.586	27	48
Gampaha	2297	2391000	2151900	2297	1.067	32	49
Kalutara	1260	1271000	1143900	1260	1.101	32	38.5
Kandy	2002	1452000	1452000	2002	1.379	39	44
Kurunegala	2112	1694000	1694000	2112	1.247	41	49
Ratnapura	1290	1151000	1151000	1290	1.121	30	43

* Population consider the proportions obtain government health sector care
**Total deaths based on the estimation for NHSL
***Per 1000 population

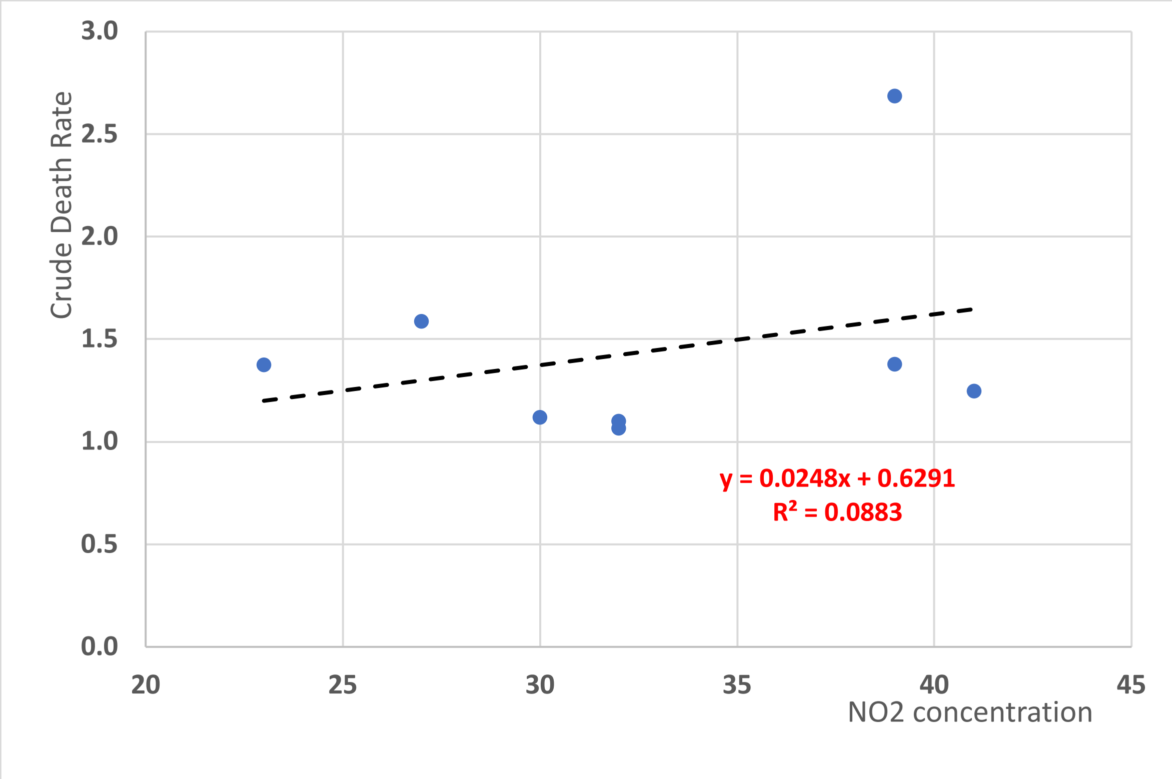


Figure 6: Correlation between death rate and NO_2 concentration

Figure 5 shows the scatter plot of the NO_2 concentration and crude death rate. The trend line shows that the with the increase of NO_2 concentration, crude death rate is increased. Increase of NO_2 concentration by 1 unit increases the crude death rate by 0.0248. In other words, increase of NO_2 concentration by 10µg/m^3 increases the deaths of 25 people prematurely per every 100,000 population. Further, it stated that the 8% of the increase of crude death rate can be explained by increase of NO_2 concentration. Crude death rate is calculated as number of deaths for the 1000 population.

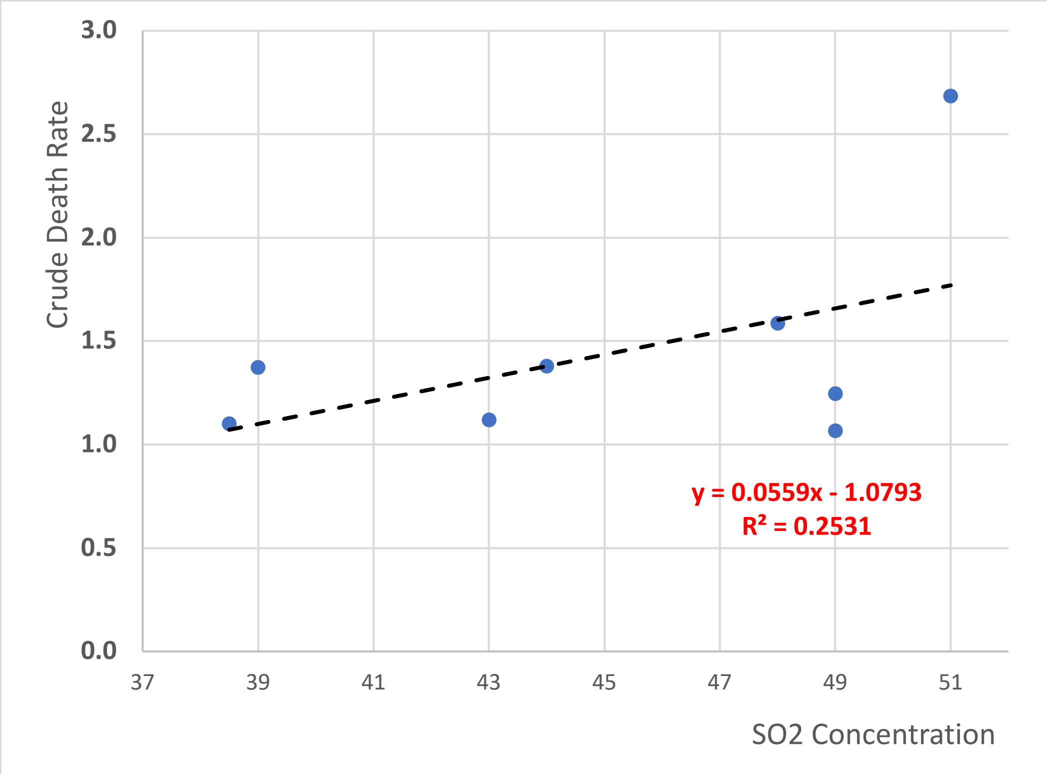


Figure 7: Correlation between death rate and SO_2 concentration

Similarly, Figure 6 shows the scatter plot of the SO_2 concentration and crude death rate. The trend line shows that the with the increase of SO_2 concentration, crude death rate is increased. Increase of SO_2 concentration by 1 unit increases the death rate by 0.0559. In other words, increase of SO_2 concentration by $10 \mu g/m^3$ increases the deaths of 56 people prematurely per every 100,000 population. Further, it stated that the 25% of the increase of crude death rate can be explained by increase of SO_2 concentration. Crude death rate is calculated as number of deaths for the 1000 population.

Component 2: Association of data from Registrar General Department and passive sampler data from the NBRO

Similar analysis was performed with the data of the Registrar General Department (RGD). Crude death rate for all causes for each district in 2017 and the SO_2 and NO_2 are provided in the table 18. However, data on age categorization of the deaths for the year 2017 is not yet available.

Table 18: Total crude death rate and air quality of selected districts

District	Total Deaths	Crude death rate	2017		Average value of 2013 to 2017	
			NO_2	SO_2	NO_2	SO_2
Anuradhapura	5,597	6.1	23	39	24.1	31.4
Colombo	23,691	7.4	39	51	43.3	36.2
Galle	8,658	7.7	27	48	31.8	32.9
Gampaha	13,943	6.5	32	49	35.4	33.4
Kalutara	8,168	7.1	32	38.5	33.5	48.8
Kandy	11,492	7.2	39	44	45.9	42.6
Kurunegala	11,189	6.9	41	49	37.2	47.2
Ratnapura	7,069	6.5	30	43	35.2	29.9

Highest crude death rate is reported from the Galle followed by Colombo and Kandy. Crude Death Rate of Sri Lanka is 6.5 for the year 2017. The table further provided the average NO_2 and SO_2 concentration reported over five years (i.e., year 2013 to 2017). However, Districts of Anuradhapura and Kurunegala are having the air quality only for two years and district of Kandy is having only for four years.

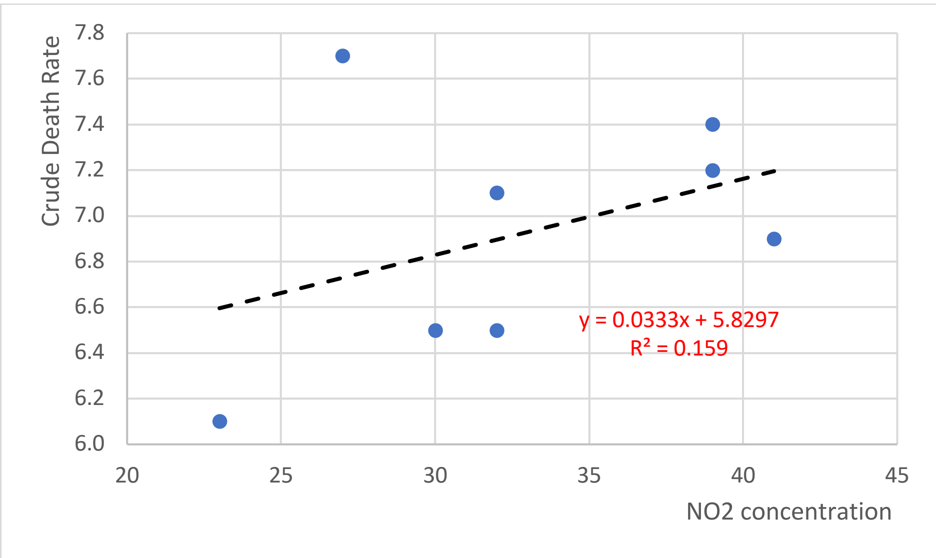


Figure 8: Crude death rates and the NO_2 concentrations (Year 2017) of the selected districts

Figure 7 shows the scatter plot of the NO_2 concentration and crude death rate of year 2017. The trend line shows that the with the increase of NO_2 concentration, crude death rate is also increased. Increase of NO_2 concentration by 1 unit increases the crude death rate by 0.0333. In other words, increase of NO_2 concentration by 10µg/m^3 increases the deaths of 33 people prematurely per every 100,000 population. Further, it stated that the 16% of the increase of crude death rate can be explained by increase of NO_2 concentration.

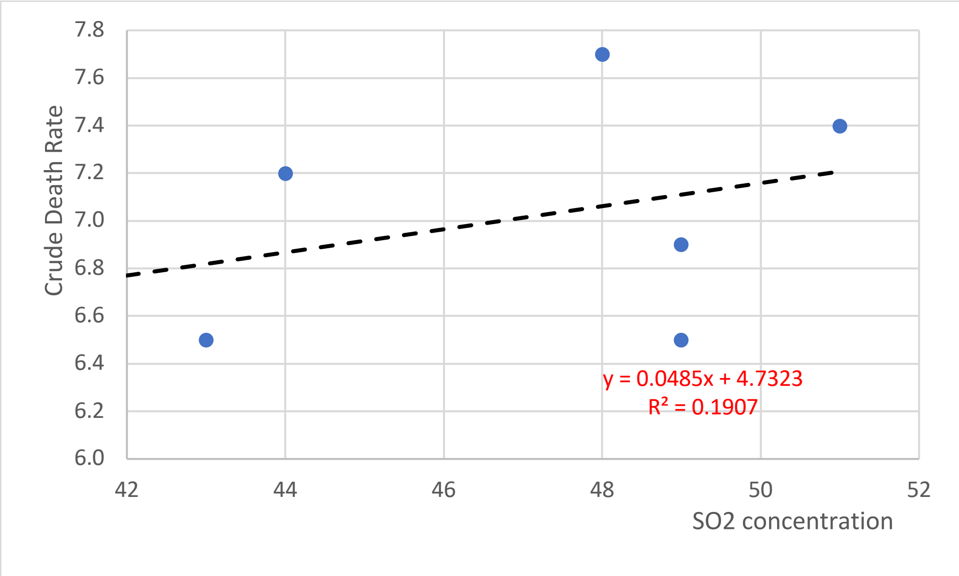


Figure 9: Crude death rates and SO_2 concentration (year 2017) of the selected districts

Figure 8 shows the scatter plot of the SO_2 concentration and crude death rate for the year 2017. The trend line shows that the with the increase of SO_2 concentration, crude death rate is also increased. Increase of SO_2 concentration by 1 unit increases the crude death rate by 0.0485. In other words, increase of SO_2 concentration by 10µg/m^3 increases the deaths of 48 people prematurely per every 100,000 population. Further, it stated that the 19% of the increase of crude death rate can be explained by increase of SO_2 concentration.

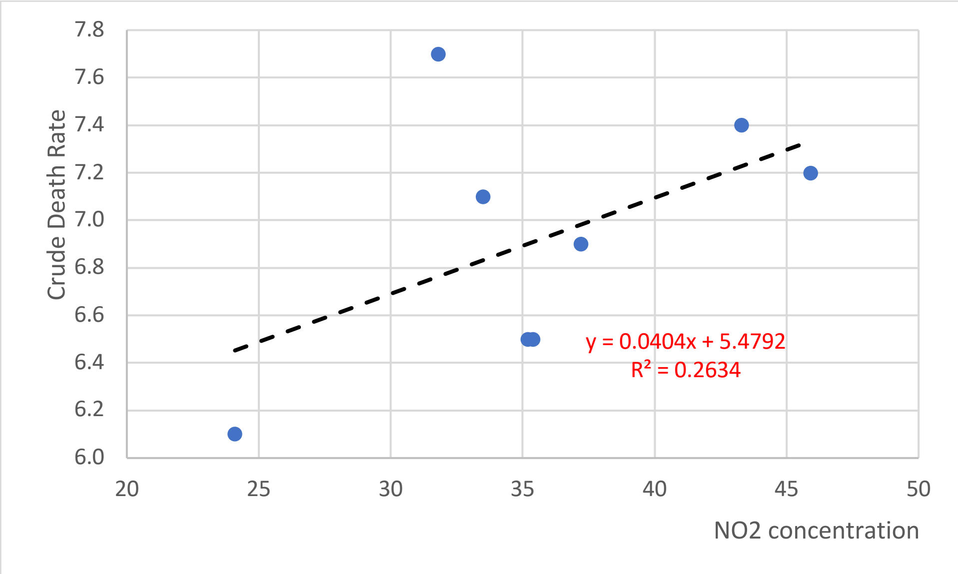


Figure 10: Crude Death Rate (2017) and average NO_2 concentration (2013 to 2017)

Figure 9 shows the scatter plot of the average NO_2 concentration (year 2013 – 2017) and crude death rate of year 2017. The trend line shows that the increase of NO_2 concentration, increases crude death rate. Increase of SO_2 concentration by 1 unit increases the crude death rate by 0.0404. In other words, increase of NO_2 concentration by 10µg/m^3 increases the deaths of 40 people prematurely per every 100,000 population. Further, it stated that the 26% of the increase of crude death rate can be explained by increase of NO_2 concentration.

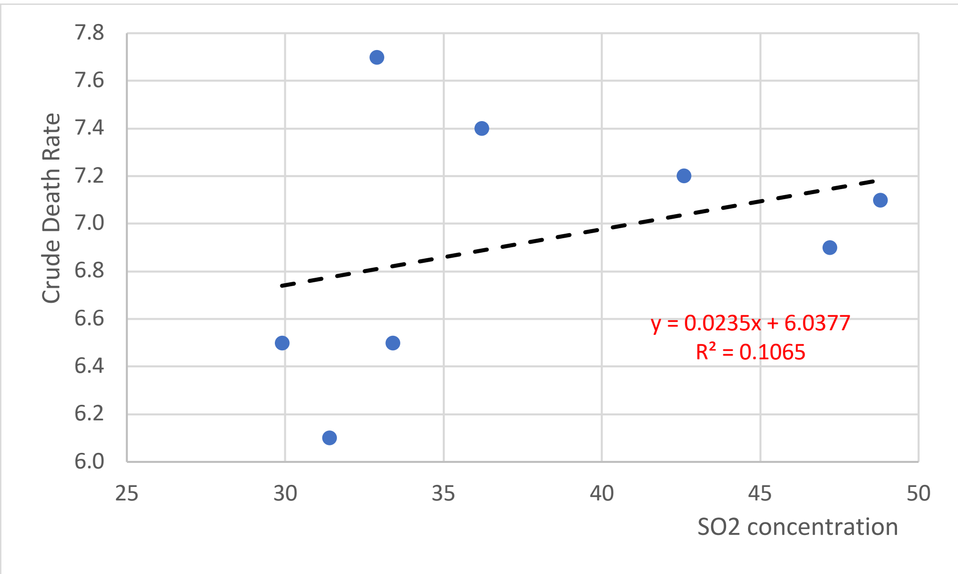


Figure 11: Crude Death Rate (2017) and average SO_2 concentration (2013 to 2017)

Figure 4 shows the scatter plot of the SO_2 concentration and crude death rate. The trend line shows that the increase of SO_2 concentration, crude death rate is increased. Increase of SO_2

concentration by 1 unit increases the crude death rate by 0.0235. In other words, increase of SO_2 concentration by 10µg/m^3 increases the deaths of 24 people prematurely per every 100,000 population. Further, it stated that the 10% of the increase of crude death rate can be explained by increase of SO_2 concentration.

Component 3: Association of data from the Electronic Indoor Morbidity and Mortality Register and Continuous data from the Central Environmental Authority (CEA)

Air quality data from continuous monitors/stations located at the Central Environment Authority premises and the Kandy were available for few months in late 2018 and early 2019. These data were correlated with the respiratory health related admissions of a health institutions. Health institution is purposely selected based on the distance to the monitor, completeness of the data at the time of data analysis and the nature of the institution (i.e., serving to the local community or tertiary care referral center).

Air quality data from the automated monitor located at the premises of Central Environmental Authority

Figure 12 shows the geocoded locations of the automated air quality monitor and the distance to the major hospitals in the surrounding area. Based on the distance, Colombo Eastern base hospital is the closest to the air quality monitor while distance from the air quality monitor to the Sri Jayawardanepura hospital, Lady Ridgway Children's Hospital, National Hospital of Sri Lanka and Kalubowila Teaching Hospital are 3.5km, 5.9km, 6.6km, and 6.6km respectively. On the other hand, these hospitals were tertiary care referral centers, thus the patients from the different parts of the country were attending to the hospitals; thus, the data represent not only the hospital admissions of the local communities. Further, data bases of these hospitals were incomplete for the data quality available period at the time of data analysis. Therefor the admissions related to the Colombo Eastern base hospital was considered in this analysis.

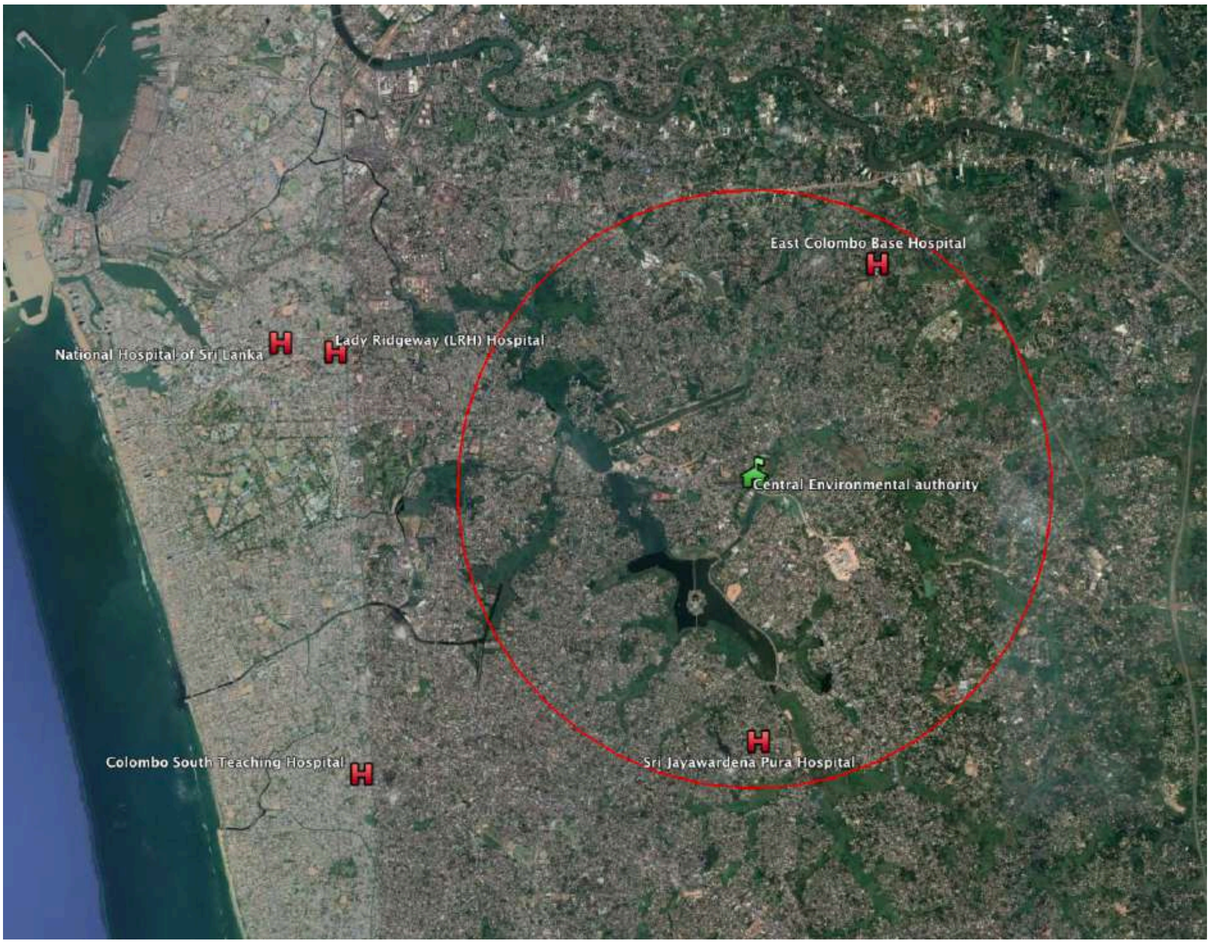


Figure 12:Location of the Air Quality monitor and major hospitals

Air pollutant concentration of 24 hours for $PM_{2.5}$, PM_{10}, NO, O_3, SO and CO for the period from 12.12.2018 to 2019.02.28 is provided in the table 19. Similarly, summary of hospital admissions is provided for the same period in table 20. There were total of 308 admission due to respiratory disease and 273 admissions of the non-respiratory related diseases during the 51 days ($PM_{2.5}$ concentration) which the air quality data is available. It should be noted, there were few days without the air quality during this period as well due to instrument failure.

Table 19:Summary of air pollutant concentrations during the monitored period (24-hour concentration values) - Colombo

Air pollutant	N	Minimum	Maximum	Mean	Std. Deviation
$PM_{2.5}$	51	11.50	147.30	47.5043	31.37540
PM_{10}	51	23.10	170.50	68.1435	32.58836
NO	52	8.24	23.54	14.7288	3.83436
O_3	52	9.64	31.33	19.1248	5.65544
SO	52	3.13	23.06	7.0610	3.69050
CO	52	0.37	1.72	0.7733	0.22481

Table 20:Descriptive statistics of the hospital admission for the period of air quality availability (from 12.12.2018 to 2019.02.28)

Disease category	Minimum	Maximum	Average	Standard Deviation
Respiratory disease	1	12	5.40	2.77
Non-respiratory diseases	0	10	4.79	2.31

$PM_{2.5}$ concentration of 24 hours was of the same day, one day prior and the two-day prior were plotted with the admissions of the respiratory diseases. Two day moving averages were considered for the graphical presentations. The best graphical correlation could be seen in respiratory admissions and the $PM_{2.5}$ concentration of two day prior to the date of admission as shown in figure 12.

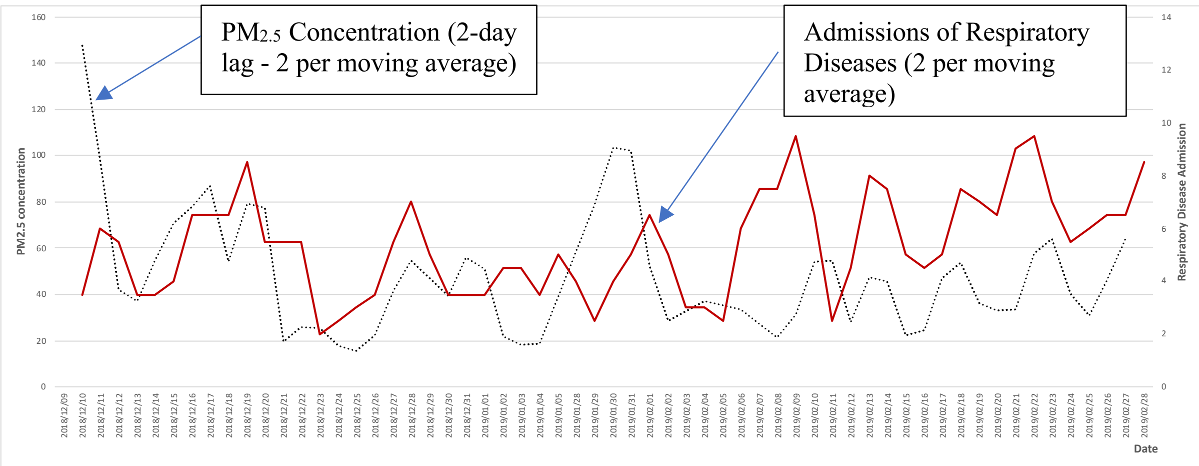


Figure 13: Relationship of the admissions of the respiratory diseases and the $PM_{2.5}$ 24-hour concentration

Air quality data from the automated monitor located at Kandy

Figure 12 shows the geocoded locations of the automated air quality monitor and the distance to the major hospitals in the surrounding area of Kandy. Based on the distance from the monitor, three of the major government hospitals are in the proximity. However, these hospitals are tertiary care referral centers, thus the patients from different parts of the country were attending to the hospitals; thus, the data represent not only the hospital admissions of the local communities. The hospitals considered in the analysis are listed below.

1. Kandy Teaching Hospital
2. Sirimavo Bandaranayake Children's Hospital

3. Peradeniya Teaching Hospital

Since the air quality was monitored from the 12.12.2018 to 02.04.2019 was available, hospital admissions of this period were obtained from the above mentioned three hospitals.

Table 21:Summary of air pollutant concentrations during the monitored period (24-hour concentration values) - Kandy

Air pollutant	N	Minimum	Maximum	Mean	Std. Deviation
$PM_{2.5}$	88	7.3	159.7	29.3813	24.35108
PM_{10}	91	18.7	187.6	61.1354	28.8047
NO	96	8.35	28.7	16.6517	4.01384
O_3	96	4.96	30.4	16.4218	5.14563
SO	96	0.13	3.01	1.5651	0.54054
CO	87	0	8.42	0.8622	0.92777

Air pollutant concentration of 24 hours for $PM_{2.5}$, PM_{10}, NO, O_3, SO and CO for the period from 12.12.2018 to 02.04.2019 is provided in the table 21. Similarly, summary of hospital admissions is provided for the same period in table 22. It should be noted, there were few days without the air quality during this period due to instrument failure. During the period of air quality monitoring, average of 31.7 admissions due to respiratory diseases and the 40.2 admissions due to non-respiratory disease associated with the air pollution exposure (Table 22)

Table 22:Descriptive statistics of the hospital admission for the period of air quality availability (12.12.2018 to 02.04.2019)

Disease category	Minimum	Maximum	Average	Standard Deviation
Respiratory disease	10	53	31.7	9.564
Non-respiratory diseases	0	131	40.2	33.107

$PM_{2.5}$ concentration of 24 hours was of the same day, one day prior and the two-day prior were plotted with the admissions of the respiratory diseases. Two day moving averages were considered for the graphical presentations. The best graphical correlation could be seen in respiratory admissions and the $PM_{2.5}$ concentration of two day prior to the date of admission as shown in figure 14.

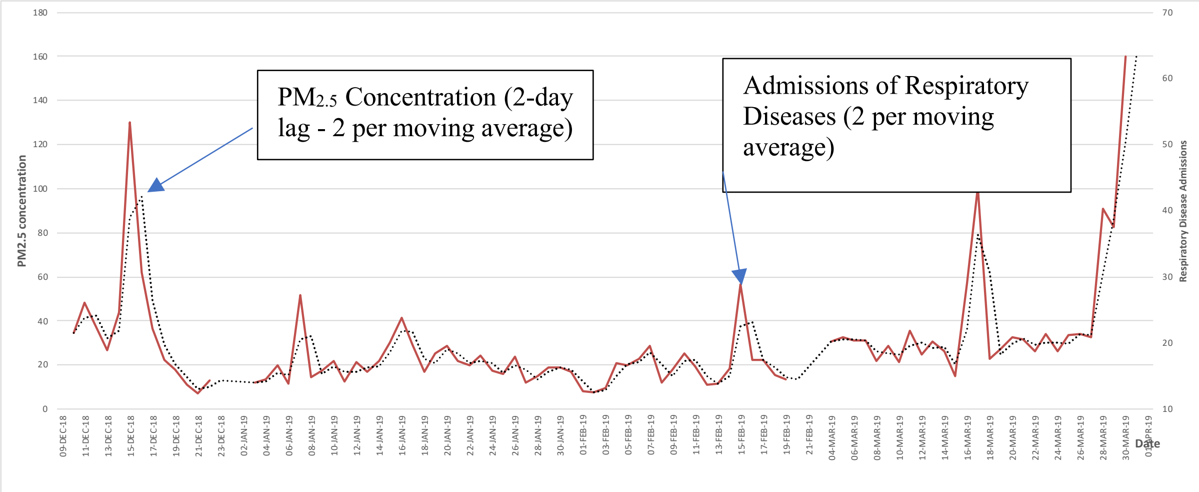


Figure 14:Relationship of the admissions of the respiratory diseases and the PM2.5 24-hour concentration – Kandy

Hospital admission of the three major hospitals in Kandy and the Peradeniya were further analyzed. The cumulative number of admissions in each day was statistically analyzed with the $PM_{2.5}$ concentration reported from the air quality monitoring. Generalized linear model (GLM) in distributed lag nonlinear modeling framework with the quasi-Poisson regression analysis was used. The analysis completed using the R software and results were visualized using the R studio software. The appropriate statistical model was chosen after the extensive literature search on similar studies. Annex 5 gives the similar ecological studies conducted in other countries and the statistical methods used in such studies.

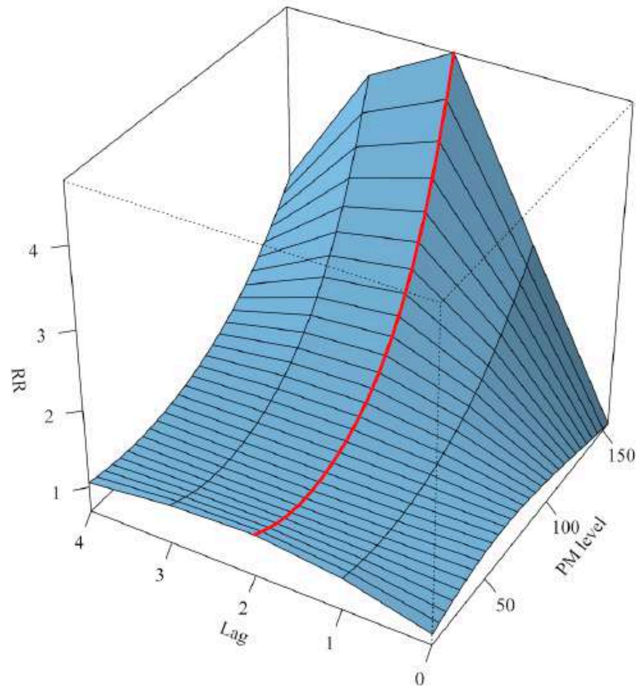


Figure 15: Three-dimensional model output showing the relative risk, particulate matter concentration and lag time of exposure for non-respiratory hospital admission.

Figure 15 shows the statistical output of association of relative risk, $PM_{2.5}$ and lag time (number of days) by modeling the daily admission date for non-respiratory diseases. The model is developed as the base value of 37.5µg/m^3 of $PM_{2.5}$ concentration. It could be noticed that as the $PM_{2.5}$ concentration increases, relative risk also increased. Highest relative risk was noticed with the lagging time of two to three days. In the other words, highest association of the $PM_{2.5}$ concentration and hospital admissions could be noticed with the exposure of 2-3 days prior to the hospital admission.

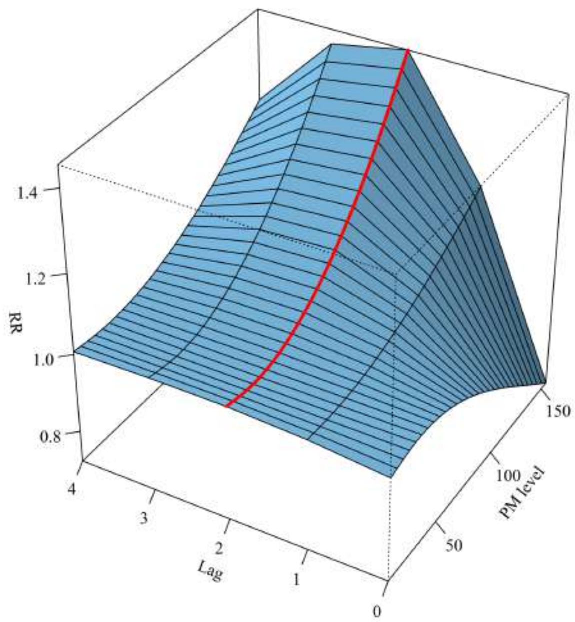


Figure 16:Three-dimensional model output showing the relative risk, particulate matter concentration and lag time of exposure for respiratory hospital admission

Similarly, figure 16 shows the statistical output of association of relative risk, $PM_{2.5}$ and lag time (number of days) by modeling the daily admission date for respiratory diseases. The model is developed as the base value of 37.5µg/m^3 of $PM_{2.5}$ concentration. It could be noticed that as the $PM_{2.5}$ concentration increases, relative risk also increased. Highest relative risk was noticed with the lagging time of two to three days. In the other words, highest association of the $PM_{2.5}$ concentration and hospital admissions could be noticed with the exposure of two to three days prior to the hospital admission. As compared to the relative risk of hospital admission of non-respiratory diseases was high as compared to the of hospital admission of non-respiratory diseases increased in the respiratory disease.

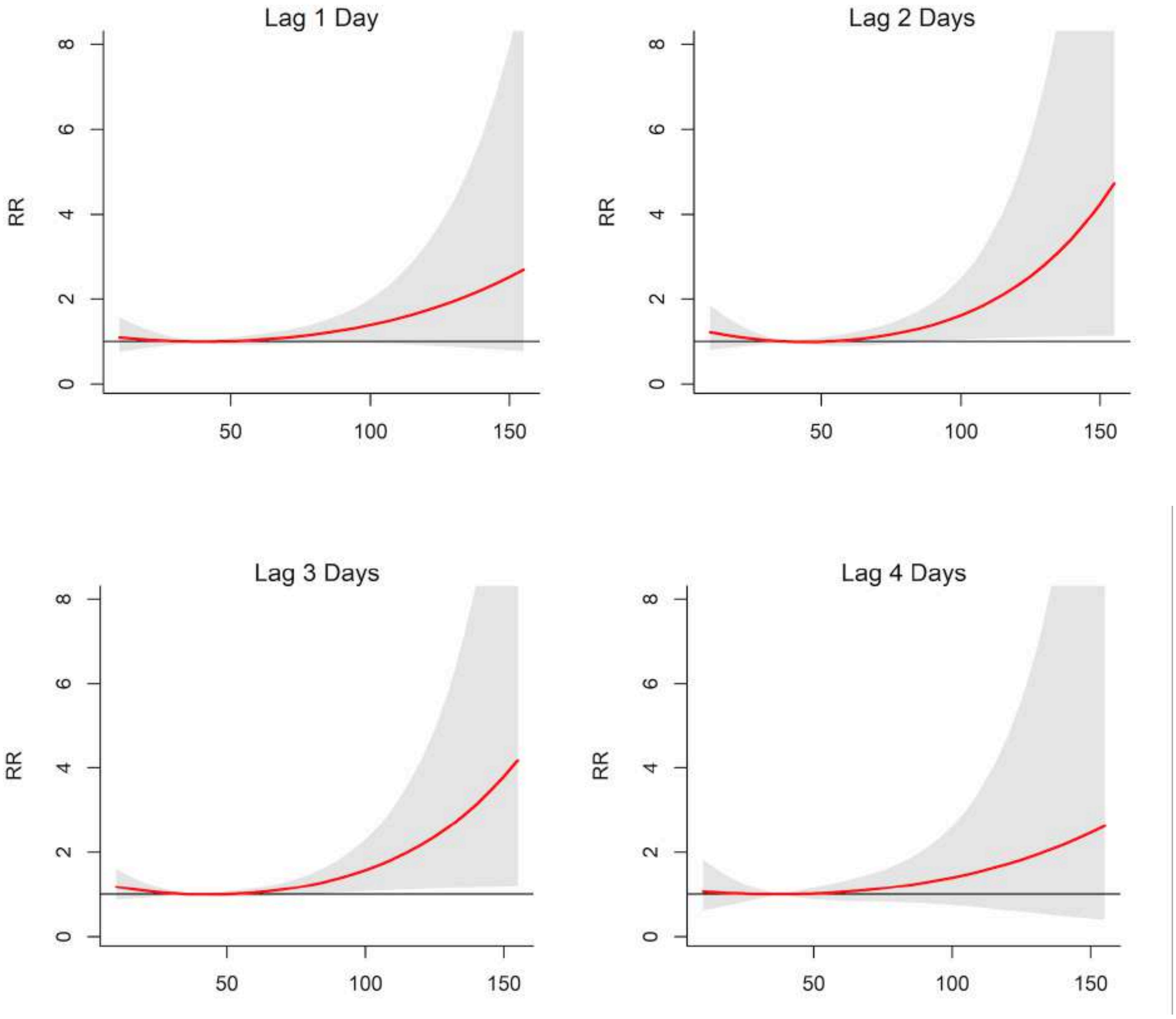


Figure 17: $PM_{2.5}$ concentration and relative risk 1 - 4 days lag for non-respiratory disease concentration (X axis represents the $PM_{2.5}$)

Figure 17 shows the increase of the relative risk of increase the hospital admission with the increase of $PM_{2.5}$ concentration. Importantly, this figure shows the confidence interval of each relative risk (dark gray colour band in figure 17) with the increase of the $PM_{2.5}$ concentration.

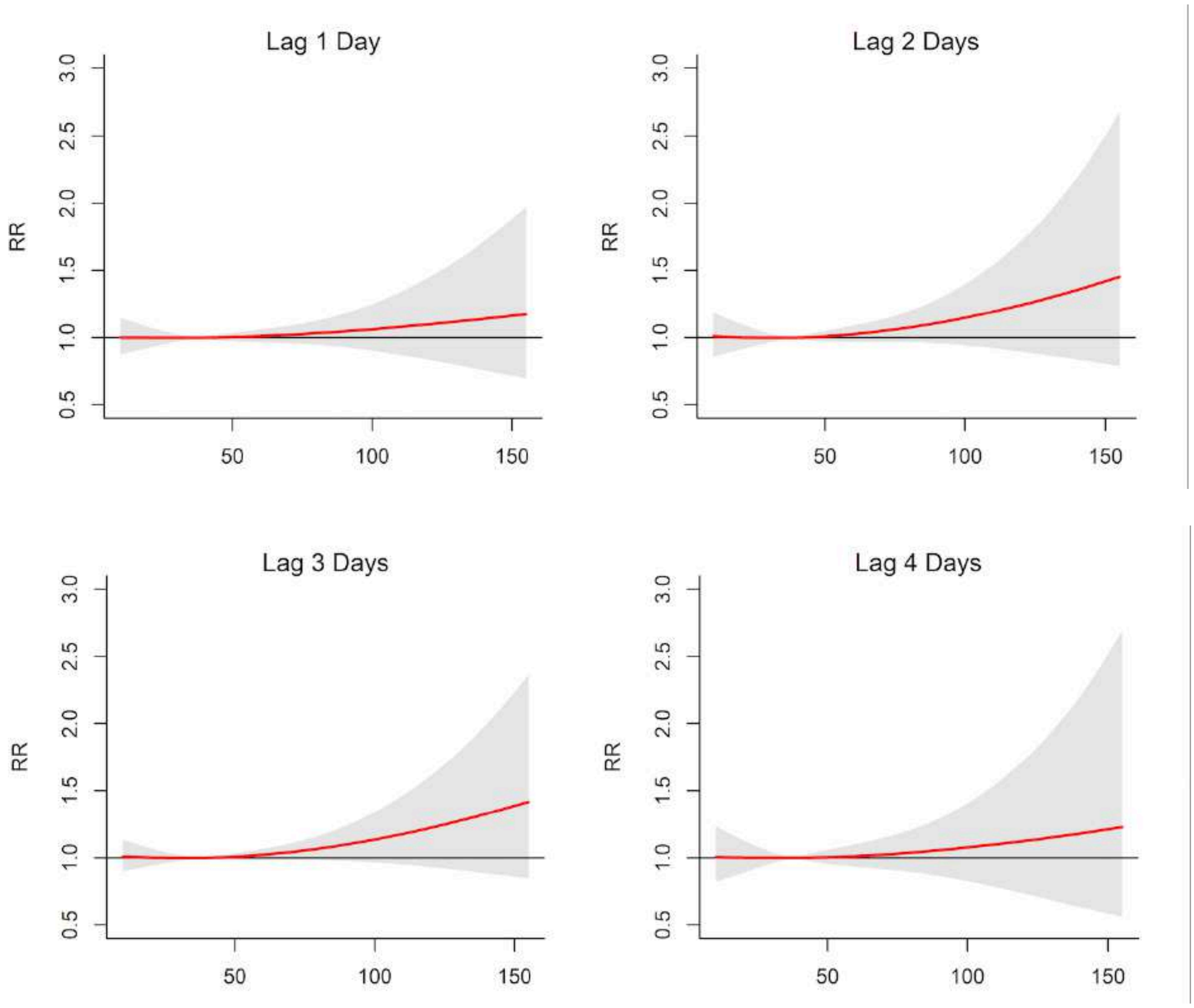


Figure 18:PM$_{2.5}$ concentration and relative risk 1 - 4 days lag for respiratory disease concentration (X axis represents the PM$_{2.5}$)

Figure 18 shows the increase of the relative risk of increase the hospital admission for respiratory diseases with the increase of PM$_{2.5}$ concentration. Importantly, this figure shows the confidence interval of each relative risk (dark gray colour band in figure 18) with the increase of the PM$_{2.5}$ concentration. However, it could be notice that the relative risk of this analysis is not significant since the confidence interval of the relative risk crosses the 1. This may be a reason of limited sample size due to the study being conducted for a short period of time.

Table 23: Relative risk of different $PM_{2.5}$ concentration for non-respiratory disease hospital admissions

$PM_{2.5}$ concentration (µg/m^3)	**RR (Confidence Interval)**
150	1.387 (1.063-1.809)
140	1.329 (1.060-1.666)
130	1.274 (1.055-1.539)
120	1.224 (1.051-1.426)
110	1.178 (1.045-1.329)
100	1.137 (1.038-1.246)
80	1.070 (1.021-1.122)
60	1.024 (1.001-1.048)
50	1.010 (0.995-1.025)
40	1.001 (0.998-1.005)
30	0.999 (0.986-1.012)

Table 23 gives the relative risk change for increasing the $PM_{2.5}$ concentration. It could be noticed that the relative risk with confidence interval of statistically significant value (which do not cross one) will be over the concentration of 50 µg/m^3. In brief, if the peak $PM_{2.5}$ daily concentrations of 150 µg/m^3 increases the hospital admissions by 1.4-fold.

Discussion

The discussion sections include several subcomponents which need to emphasize and discuss in detail.

Uniqueness of the study

According to the extensive literature search, this is the first ecological study represent the nationwide data in Sri Lanka related to air pollution epidemiology. The results presented in this analysis carry significant uncertainties but constitute the best possible scientific methods for limited data. Although the electronic data sets were available for almost all institutions for indoor patient care in the government allopathic health sector, scarcity of air quality data in some districts limit the analysis. Despite the limitations, associations could be assessed for eight districts which have the air quality data. Particularly, many of the health impact studies have conducted as the time series studies. Such studies need to have continuous air quality data as well as daily hospital admissions. Although the Sri Lankan government health sector have the continuous admission data, continuous air quality data was lacking for a substantial period of time. Therefore, unique methodology was used to compare the air quality levels across the and the hospital admissions across the country. Hospital admissions were considered in the three major categories of the diseases based on the ICD 10 as shown in figure 19.

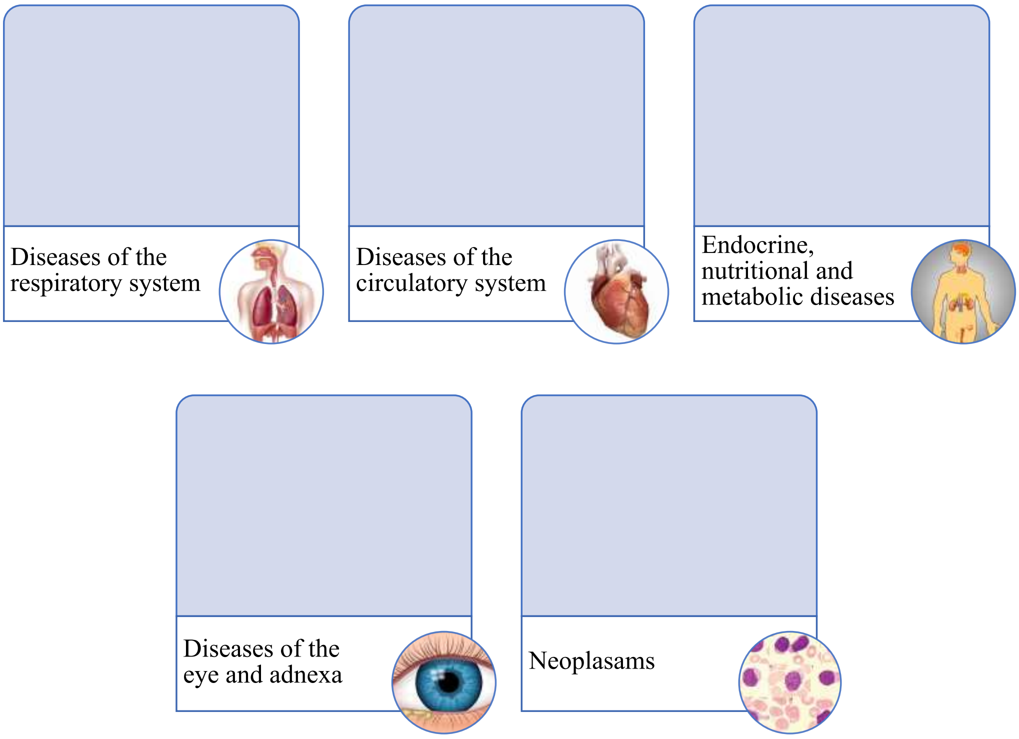


Figure 19: Disease categories considered in the data analysis

Results summary, interpretation and assumptions

Analysis shows that there are association with both NO_2 and SO_2 concentrations and the reported deaths rates in the different districts. Importantly, first component of the study (i.e., Association of data from the eIMMR and passive sampler data from NBRO)
do not

Analysis was completed based on the data sources as (1) eIMMR of the Ministry of Health which represent the information on the admitted patients to the government hospitals in Sri Lanka and (2) Information on civil registration system (i.e., deaths) from the RGD. Both data sources were considered for the year 2017. In addition, daily admissions for respiratory diseases were correlated with the daily air quality data received from the automated air quality monitors. In Colombo, respiratory diseases admissions at the Eastern Colombo base hospital and air quality data from the automated monitor at the premises of the CEA was correlated. In Kandy, air quality data at the city of the Kandy were correlated with the respiratory admissions of the three government hospitals in Kandy and Peradeniya.

As an advantage of the eIMMR, the deaths were available with the ICD – 10 classification. Therefor the deaths related to the disease known to associated with the air pollution was identified. There were 556401 admissions in health institutions of the selected eight districts related to the diseases associated with the air pollution. Analysis of eIMMR shows, increase of NO_2 concentration by 10µg/m^3 increases the deaths of 25 people prematurely per every 100,000 population. Similarly, increase of SO_2 concentration by 10µg/m^3 increases the deaths of 56 people prematurely per every 100,000 population.

Information from the RGD for the year 2017 was not available for the ICD classification -10 at the time of data analysis of the present project. However, as an advantage of the information from the RGD data, available data include all deaths (i.e., deaths in the hospitals and the deaths in the community). The analysis shows, increase of NO_2 concentration by 10µg/m^3 increases the deaths of 33 people prematurely per every 100,000 population; and increase of SO_2 concentration by 10µg/m^3 increases the deaths of 48 people prematurely per every 100,000 population. Further the analysis was extended for five-year exposure levels of NO_2 and SO_2. Results show, increase of NO_2 concentration by 10 µg/m^3 increases the deaths of 40 people prematurely per every 100,000 population; and increase of SO_2 concentration by 10µg/m^3 increases the deaths of 24 people prematurely per every 100,000 population.

Comparison of values shows a variation of the deaths which can be predicted through the limitations and methodological differences in the collection of data bases. The reasons for differences in the deaths rates for same pollutant could be as below.

(1) eIMMR was only based on the hospital deaths while the RGD data is based on deaths occur in both the community and the health institutions (allopathic government and the private sector; allopathic as well as the other medical streams such as Ayurvedha)
(2) eIMMR data was filtered for the deaths of air pollution related diseases while the RGD data is based on the whole cause mortality (i.e., deaths due to any reason and disease).
(3) Deaths were reported base on the place of occurrence for both data bases. There can be overlapping of the deaths across the districts and exposure misclassification could be happened to various degrees.
(4) In the case of eIMMR, hospital-based ICD coding system was considered. The probably the "cause of death" may be different from the "underlying cause of death". The data recording system consider the cause of death. This may lead to over or under classify the number of deaths from the air pollution related disease.

Table 24: Summary of excess deaths (per 100,000population) for increase of NO_2 and SO_2 based on two sources of health data

	Source		
10µg/m^3 Increase	eIMMR	RGD	
Pollutant exposure period	Year 2017	Year 2017	Year 2013-2017
Deaths for NO_2	25	33	40
Range of deaths for NO_2		**25 to 40**	
Deaths for SO_2	56	48	24
Range of deaths for SO_2		**24 to 56**	

Table 23 provide summary findings of two data sources. In the case of 2017 air quality levels, SO_2 shows more excess deaths as compared to NO_2. Studies in other countries have also shown higher adverse health outcomes from SO_2 as compared to NO_2 (Ren & Tong 2008). In summary, 10µg/m^3 increase in NO_2 concentration results in 25 to 40 excess deaths while 10µg/m^3 increase in SO_2 concentration results in 24 to 56 excess deaths (Figure 20).

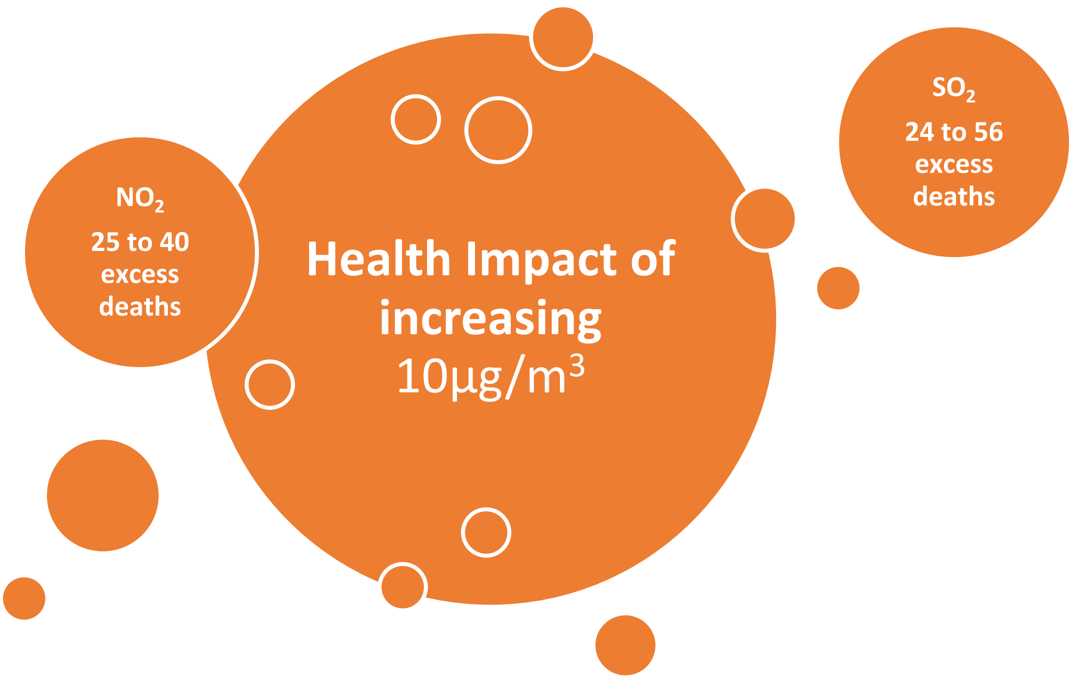


Figure 20: Graphical summary of number of excess deaths for the increase of 10µg/m^3 of NO2 and SO2

Reported NO_2 and SO_2 concentration vs. WHO guideline values

Reported NO_2 concentrations in Sri Lankan cities/districts varied from 23 to 41 µg/m^3 and SO_2 concentration in Sri Lankan cities/districts varied from 38.5 to 51µg/m^3. In the case of NO_2, reported values were either lower than or almost similar to the WHO guideline value(WHO 2006).

Table 25: Comparison of reported air quality levels with the WHO guideline value and the Sri Lankan standard

Pollutant	Reported concentration	WHO guideline value	Sri Lankan Standard
NO_2	23 to 41	40	100*
SO_2	38.5 to 51	20*	80*

* 24-hour average value of year 2017

Although the reported value of NO_2 and SO_2 concentration cannot compare directly with the Sri Lankan standards (Sri Lankan standard available for the 24 hours), it is much higher than the monitored concentration. In fact, reported values were close to the WHO guideline value. Similar studies from other countries have reported that the air quality concentration similar to the WHO guideline values shows the adverse health effects. In this context, it is recommended to revise the Sri Lankan standards for NO_2 which is much higher than the reported value. Further, it is recommended to have an annual mean value for NO_2 concentration, similar to the WHO guidelines which enable the comparison of annual averages.

Reported SO_2 concentration cannot be directly compare with the WHO guideline value and the Sri Lankan standards since both are stated as the 24-hour average value. However, it could be noted (table 25) that the reported values are over the WHO guideline values but less than the Sri Lankan standards. Therefor it is recommended to revisit the Sri Lankan standard in view of revision to protect the public. Table 26 gives the Sri Lankan air quality standards based on the Gazette no- 1562/22 on 15th Friday, August 2008.

Table 26:Sri Lankan air quality standards

Pollutant	**Averaging time**	**Maximum permissible value ($\mu g/m^3$)**
PM_{10}	Annual	50
	24hours	100
$PM_{2.5}$	Annual	25
	24hours	50
NO_2	24hours	100
	8hours	150
	1 hour	250
SO_2	24hours	80
	8hours	120
	1 hour	200
O_3	1 hour	200
CO	8 hours	10000
	1 hour	30000
	Any time	58000

Air pollution can be broadly divided based on the source as outdoor air pollution and indoor air pollution. Outdoor air pollutants are emitted from a variety of sources including traffic and other transportation, agriculture, wildfires, and industry. Consequently, the general population is exposed to a heterogenous mixture of particles and gases with varying chemical constituency. The different parameters are changed from one district to the other which determine the total exposure levels. Although the mixture of air pollutants could be affected the exposure, NO_2 and SO_2 were taken in the comparison of districts since data on other pollutants are not available.

Reported $PM_{2.5}$ concentration vs. WHO guideline values

Daily $PM_{2.5}$ concentration from 12.12.2018 to 2019.02.28 of automated monitor at the premises of the Central Environmental Authority was correlated with the daily respiratory admissions of Eastern Colombo Base Hospital. I addition, daily $PM_{2.5}$ concentration from 12.12.2018 to 02.04.2019 of automated monitor located at the Kandy city area was correlated with the daily respiratory admissions of three hospitals at the Kandy and the Peradeniya area. Both shows correlation to an extent (figure 13 and figure 14). Limited availability of the data does not allow to conduct time series analysis in an effective manner. However, it should be noted that the most effective as well as widely use method of analysis for the secondary data with the daily hospital admission (or deaths in the hospitals) data is "time series analysis". However, such studies have used the air quality and the daily hospital admission data for years. As an example, "association of between ambient $PM_{2.5}$ and children's hospital admissions for the respiratory diseases in Jinan, China" (Liu et al, 2019) was analyzed over four years (year 2011 to year 2015).

Table 27: Comparison of $PM_{2.5}$ and PM_{10} with the Sri Lankan and WHO guideline values (24-hour average)

Pollutant	Colombo Ave. (Max.)	Kandy Ave. (Max.)	WHO guideline value	Sri Lankan Standard
$PM_{2.5}$	47.5 (147.3)	29.4 (159.7)	25	50
PM_{10}	68.1 (170.5)	61.1(187.6)	50	100

$PM_{2.5}$ concentration of automated monitors in Colombo (at the premises of the Central Environmental Authority) and the city of Kandy gave the opportunity to compare the exposure levels. As shown the by the table 27, average values of the both locations exceed the WHO guideline values although it is lower than the Sri Lankan standards.

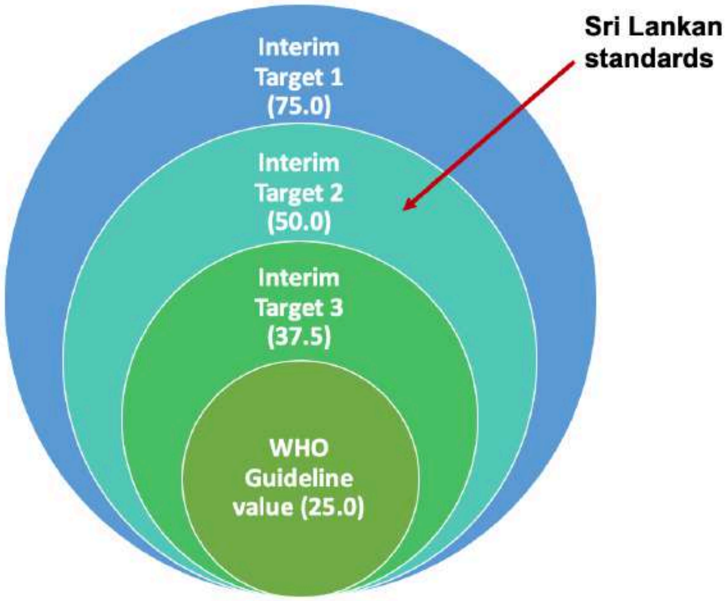


Figure 21: WHO guidelines and the Sri Lanka standards for 24-hour $PM_{2.5}$ concentration

As shown in the figure 21, Sri Lankan standards of the air quality is at the interim target 2 of the WHO air quality standards. Reported $PM_{2.5}$ concentration in both Colombo and Kandy are correlated with the hospital admissions. it is recommended to revisit the Sri Lankan standards in view of revising them. Further, it should be noted that base on the monitored air quality levels, PM concentration in Colombo is higher than the Kandy; though the commonly believe public opinion is Kandy's air quality level is the worst in the country.

Advanced statistical modelling of $PM_{2.5}$ concentration at the city of Kandy

Continuous data available for limited number of days were modeled with the daily hospital admissions of the city of Kandy. This advanced statistical analysis would be important for some critical policy decisions. Generalized linear model (GLM) in distributed lag nonlinear modeling framework with the quasi-Poisson regression was used in this analysis. In this analysis, base value was taken as 37.5 $\mu g/m^3$; the interim target 3 of the WHO guideline value for 24 hours. It could be noticed that highest association of 24-hour $PM_{2.5}$ concentration and the hospital admission could be seen at the lag of $PM_{2.5}$ concentration in two to three days. Figure 22 shows the variation of daily $PM_{2.5}$ concentration over the monitored period. Importantly, there were increase of the $PM_{2.5}$ concentration over 50 $\mu g/m^3$ during the monitored period. When the $PM_{2.5}$ concentration peaks over 50 $\mu g/m^3$, hospital admissions were significantly higher than the other days.

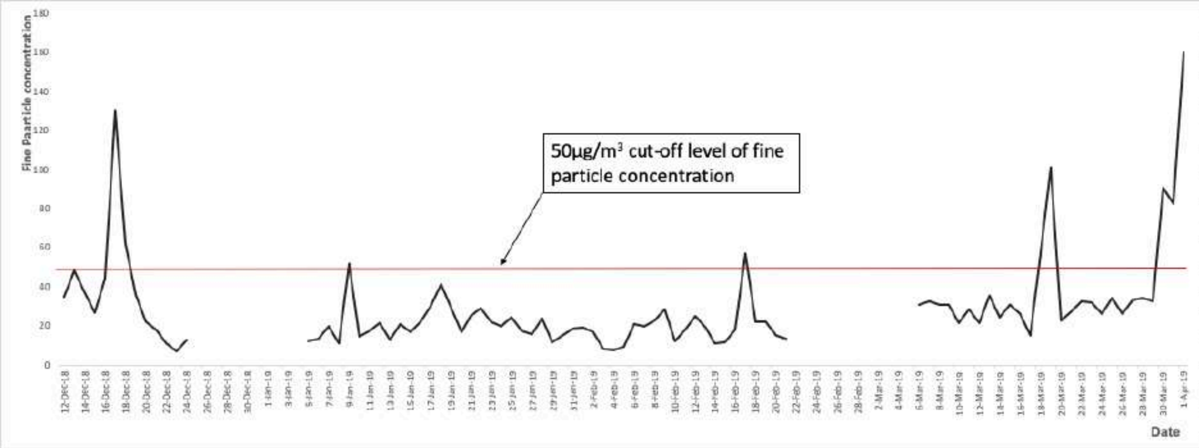


Figure 22: Daily $PM_{2.5}$ concentration cut-off over the 50µg/m³

<u>Clean air action plan –2025 and prioritization of the activities</u>

Importance of further reduction of the outdoor air pollution is highlighted in the results. Specifically, the areas with high exposure levels. Clean air action plan – 2025 of Sri Lanka identified the activities to be implemented to reduce the air pollution exposure in Sri Lanka. Briefly the action plan identified 12 thematic areas to be implemented. Identified thematic areas are as below.

1. Institutional framework for strategic management and coordination of AQM
2. Effective management of Air emissions from Transportation sector
3. Effective management of Air Emissions from Stationary Sources
4. Indoor Air Quality Management
5. Management of Unethical & Unintentional Practices
6. Cleaner Technologies, Fuels and Processes
7. Air Quality Monitoring
8. Awareness, Education, Information and Knowledge Management for Air Quality
9. Research, Development fostered and Impact Assessment of Air Pollution
10. Development of Information Knowledgebase & Human Resources for Effective AQM
11. Global Participation & Collaboration for AQM
12. Sustainable Financing Mechanism for AQM

Each thematic area is having many activities. All the activities are important to minimize the air pollution in Sri Lanka. While it is not rational to prioritize individual activities based on the findings of the report, it may necessary to expedite the actions and to identify the lagging actions. Specifically, it is necessary for early implementation of the activities identify under the (2) Effective management of air emissions from transportation sector and (3) Effective management of air emissions from stationary sources including the sources of indoor air pollution. Studies show that the indoor air pollutants contribute to outdoor air.

<u>Air quality monitoring in Sri Lanka</u>

Status of air quality monitoring, sources of data of air quality, associations of monitored air pollutants, stakeholders of air quality, etc. are given in a separate consulting document. However following paragraph would explain the some of the concerns were raised this assignment.

Passive samplers are widely used in the monitoring of air pollutants. They give the opportunity to monitor the air quality in a low cost and low resource remote locations (e.g., electricity not needed). However, there were limited cities of Sri Lanka were having the passive samplers. Further, considerably low number of passive samplers available for representing each district. The analysis performed in this study were mostly limited to passive samplers, this importance is strongly felt. While it is necessary expand the passive sampler network, it is recommended that the passive sampler network is linked with the active samplers. This will able to conduct the population based epidemiological studies with less exposure misclassification.

Usually, patterns of air pollution are driven by weather. Concentrations of air pollutants may be associated with temperature. Therefore, it may be possible that temperature and air pollution interact to affect health outcomes. Although effect modification could be done with a such parameter, it is complex phenomenon. Sri Lanka being a tropical country, although the temperature change from wet zone to dry zone and to the central part; the changes to gain a statistical inference is minimum.

Indoor air pollution

Air pollution epidemiologic research is challenged by the complexity of human exposure to environmental agents and by the difficulty of accurately measuring exposure. Residents are usually universally exposed to air pollution. However, indoor air pollution is based on the household conditions and the practices. As an example, if the household use wood for cooking, and smoking with the households, it may lead to increase the indoor air pollution. Similarly, if the household not having an adequate ventilation including the door, windows and chimney, it will lead to increase the indoor air pollution. Further the exposure level based on the amount of time spend indoors. Although it is not possible to count this individual variation, it could be noted that this is a limitation of study designs and statistical methods use in the present data analysis.

Even though the association of outdoor air pollution with health outcomes is weak, it still has strong public health implications. One reason is that air pollution is universally affects the whole population, especially in urban settings of Sri Lanka. Importantly, air pollution is a modifiable risk factor. The remedial actions and policy implications had shown the actual public health benefits of the air pollution. Some of the interventions have shown that the reduction in air pollution has resulted in an improvement in population health(S Nandasena et al. 2012) For example, a study reported that cardiovascular, respiratory and all-cause mortality reduced by 2.0% ($p < 0.05$), 3.9% ($p < 0.05$) and 2.1% ($p < 0.05$) respectively in the first 12 months after an introduction of the restrictions on Sulphur content of fuel in Hong Kong (Hedley et al. 2002).

Confounding factors/variables in the assessment

Both the air quality level and the hospital admission are confounded with different factors. As few examples, air quality levels change with the climatic factors such as temperature and daily and weekly pattern of work. It is a well know factor that the air quality level changes with the seasonality. Also, the air quality level deteriorates weekdays as compared to the weekends due to differences of pattern of work. Air pollutants not act on the body as separate pollutants. But they do act synergistically. On the other hand, hospital admissions due to the different diseases have different risk factors. As an example, it is well knowing the risk factors of heart disease are bad dietary pattern, mental stress, lack of exercise, smoking, etc. This risk factors may or may not act separately on the human body. This discussion shows that there are many factors affect the association of exposure to air pollution and the health impact. Perhaps these known factors are attempted to neutralize by the statistical methods (e.g., multivariate analysis). However, it could be noted that the most important is the strength of association of air pollution exposure and the health impact. Although, many other factors are affected the air pollution exposure level, it is immaterial in this analysis, since the main objective is to identify whether the existing exposure levels impact the health of population. If so, the need to identify the strategies for reducing the air pollution. Further, it should be noted that the intention of this project is to understand whether the existing exposure levels significantly associated with the health impacts; rather conducting to assess the relationship of air pollution and health.

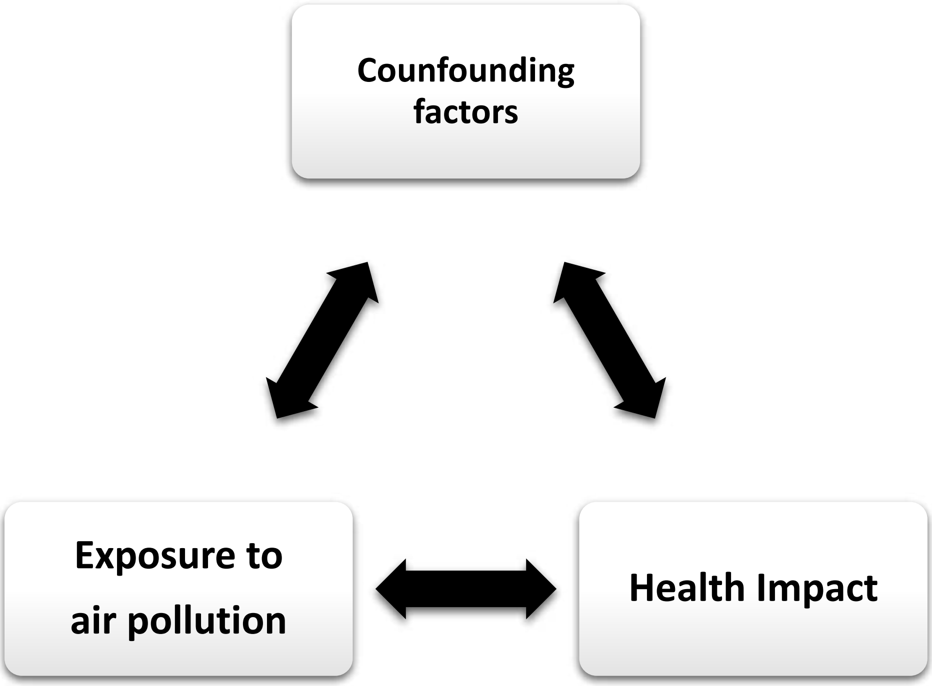


Figure 23: Relationship of the exposure to air pollution, health impact and the confounding factors

Limitations

This study has also several limitations as explained below.

Study design:

There is an association between hospital deaths due to air pollution related diseases and ambient NO_2 and SO_2 concentration. However, the design of the study is ecological. Ecological association does not allow to make any inference about causal relationships.

Exposure misclassification:

As many other ecological studies, air quality levels were considered for a district, a large geographical basis. This may have misclassified the individual exposure levels. As an example, the people in certain locations with the district would not have same exposure levels as the calculation considered.

Limited number of districts:

Although the health data is available for each district of Sri Lanka, analysis was limited to nine districts which have the air quality data.

Unavailability of continuous monitoring data of air quality:

The health data for admitted patients for the hospitals available on daily basis. However, air quality data is not available for the daily basis other than the data received from the CEA for a short period. That was due to lack of the continuous monitoring. NO_2 and SO_2 were available only from the passive samplers of the selected districts. These passive samplers gives the average air quality levels of one month period.

Community based deaths are not counted:

The recoding system of the Ministry of Health, Sri Lanka include only the hospital deaths. However, some of the deaths could be happened in the community. These deaths are not counted in the analysis. Although, these deaths are counted in the data sources of registration of deaths (i.e., Registrar General Department), electronic data set is not available for the near future.

Overlapping of the patients attend to the hospitals:

Health system of Sri Lanka do not have a empanelment of the population. Therefor the patients can by-pass the certain hospitals and get the admitted to the hospital of their choice. This may cause the patients to record in a hospital which is not in their residential location. This may lead to misclassification of the outcome and the exposure.

Limited number of passive samplers

The number of passive samplers in the districts which are having the air quality were limited. This tended to estimate the air quality in the entire district based on the air quality of relatively small geographical area. This may lead to the exposure misclassification.

Hospital data (i.e., eIMMR) sources Vs. registrar general department data

Both data set has its own limitations. The hospital data is limited to the deaths occurred in the hospitals. However, there can be deaths happen in the community as well. The information is not available in the eIMMR. On the other hand, as described previously, there can be overlapping of the patients. RGD data includes all the deaths registered. This civil registration is required for other future endeavors of the diseased person (e.g., acceptance of the body to a cemetery belongs to the local authority, legislation of assets of the diseased person, etc.). However, the deaths are registered at the place of occurred, thus essentially it may not at the place of residence. As an example, A person from Wadduwa is admitted to the National Hospital of Colombo (NHSL), if died at the same hospital, the death will be registered at the death registrar responsible to the area of NHSL.

Conclusions and recommendations for policy implications

Conclusions

- NO_2 and SO_2 concentrations and the deaths were positively corelated. In other words, while the air quality levels deteriorate, more health outcomes were reported.

- Analysis of eIMMR (year 2017) shows, increase of NO_2 and SO_2 concentration by 10µg/m^3 increases the deaths of 25 people and deaths of 56 people respectively per every 100,000 population.

- Analysis of RGD data (year 2017) and the air quality data of year 2017 shows increase of NO_2 and SO_2 concentration by 10µg/m^3 increases the deaths of 33 people and deaths of 48 people respectively per every 100,000 population.

- Analysis of RGD data (year 2017) and the air quality data of (year 2013 to 2017) shows increase of NO_2 and SO_2 concentration by 10µg/m^3 increases the deaths of 40 people and deaths of 24 people respectively per every 100,000 population.

- Based on the findings of the both sources of health data, impact of 10µg/m^3 increase in NO_2 concentration results in 25 to 40 excess deaths while 10µg/m^3 increase in SO_2 concentration results in 24 to 56 excess deaths per 100,000 population.

- Health effects are reported and showed an association for NO_2 and SO_2 at the concentrations below the Sri Lankan standards.

- Number of deaths associated with NO_2 and SO_2 concentration is higher than the deaths due to other diseases. Among the disease associated with air pollution, highest number of admissions were due to the respiratory diseases.

- Average daily $PM_{2.5}$ concentration resulted from the automated monitors at the Colombo and Kandy were higher than the WHO guideline values; and exceeded the Sri Lankan standards in some days during the monitoring period.

- Compare to the daily $PM_{2.5}$ concentration in Kandy, City of Colombo have the higher levels, confirming that Colombo is polluted than the city of Kandy.

- Respiratory diseases related admissions in government hospitals of both Kandy and Colombo were associated with daily $PM_{2.5}$ concentrations from automated monitors in the close proximity.

- Hospital admission for the non-respiratory diseases were significantly associated with the daily $PM_{2.5}$ concentration in the city of Kandy. Hospital admission for the respiratory diseases were shown a positive association with the $PM_{2.5}$ concentration; but not significant.

- Association of hospital admissions were highest for the two to three days prior $PM_{2.5}$ daily concentration.

- With the increase of daily $PM_{2.5}$ concentration to the level of 150 $\mu g/m^3$, hospital admissions are increased by 1.4 folds.

- When the $PM_{2.5}$ concentration peaks over 50 $\mu g/m^3$, hospital admissions were significantly higher than the other days.

Recommendations

The recommendations of the study focus mainly on reduction of health impact due to outdoor air pollution and strengthening the exposure assessment for future health impact studies (Figure 24).

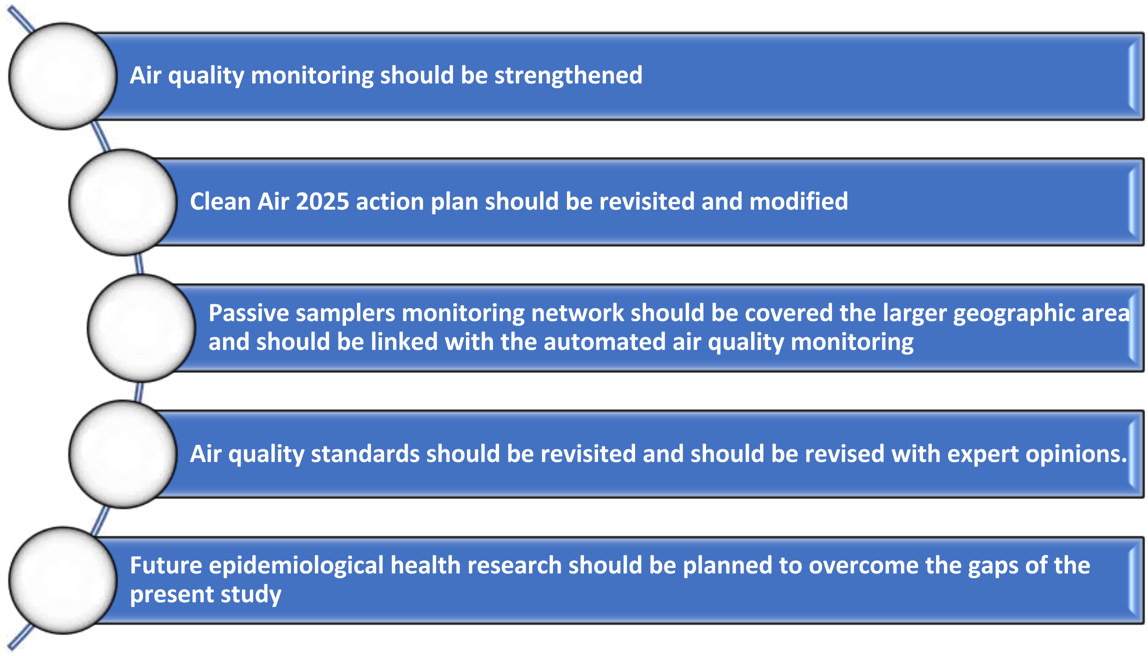


Figure 24: Key Recommendations

Air quality monitoring should be strengthened

The data availability for air quality levels are extremely limited. This lead to the analysis to be limited to eight districts and the two pollutants (i.e., NO_2 and SO_2). Outdoor PM levels were not available for the different locations of the country; the most hazarded air pollutant. Further, NO_2 and SO_2 concentrations were only available as passive samplers. In fact, the scarcity of the air quality data limit this health impact analysis. Possibly this greatly limit the impact evaluation of the actions implemented to minimize the air pollution at the national level.As an example, vehicle emission testing programme which utilizes a substantial amount of public money cannot be evaluated since the lack of monitoring in Sri Lanka. Therefore it is strongly recommended that the air quality monitoring network of Sri Lanka should be strengthened and linked among the different stakeholders (e.g., Central Environment Authority, National Building Research organization, etc.).

Clean Air 2025 action plan should be revisited and modified

Many activities identified in the Clean Air 2025 action plan to further minimize the air pollution in Sri Lanka. It is recommended to go through each activity and identify the activities implemented to date. It is necessary to identify the activities "missed" to implement based on the Action Plan 2025. According to the knowledge, some of the activities have passed the time line, but not implemented/completed. As an example, most of the activities identified under the section 3 of the Action Plan 2025 (i.e., Effective Management of Air Emissions from Stationary Source) which included the time frame of year 2016 to 2018, has not being implemented. Further, it is necessary to revisit the proposed activities in the Action Plan 2025 in view of adding the new activities, modify the time line, and modify the activities based on the present and future plans of the government of Sri Lanka. It should give the more emphasis on following sections and their sub activities to overcome public health impact early. The sections are

1. Institutional framework for strategic management and coordination of AQM
2. Effective management of Air emissions from Transportation sector
3. Effective management of Air Emissions from Stationary Sources

Passive samplers monitoring network should be covered the larger geographic area and should be linked with the automated air quality monitoring

It was realized that the passive samplers in each district is limited and focus on only one/two major cities. This will limit the clear understanding of air quality levels in the rural locations and the certain cities. Therefore it is recommended to increase the locations of passive samplers. While understanding this activity is practically not feasible for one institution, it is recommended to have more widen multi institution commitment multi funding for this purpose. In the absence of continuous monitoring, improving passive samplers network for covering of the rural areas and the cities (i.e., cities which are not planned to establish continuous monitoring) will be useful for understanding the air quality in all regions of Sri Lanka cost-effectively.

Air quality standards should be revisited and should be revised with expert opinions.

It could be noticed that the reported NO_2 and SO_2 concentrations are lower than the Sri Lankan standards. Further, there is no annual mean for NO_2 in Sri Lanka although it was available from the WHO guideline values. Air quality standards in Sri Lanka was revised in year 2008; over 10 years back. Sri Lankan standards are par with the interim target two of the WHO guideline values. Since the socio-economic context and the technology have changed over the years, it is recommended to revisit the Sri Lankan standards in air quality with considering the revisions.

Future epidemiological health research should be planned to overcome the gaps of the present study

One of the key actions identified in the Clean Air 2025 is “research, development fostered and impact assessment of air pollution”. Certain actions are fulfilled in this activity by the present study. However, it is necessary to further enforce the other actions. Fostering of research would facilitate the implementation of other activities in the Clean Air 2025. The present study is seriously suffering by study design and other methodological issues due to several issue which were described under the limitations. It is important to conduct further studies with overcoming these methodological issues. Use of the national level data sources mainly focus on ecological studies or semi-ecological studies in study designs need to promoted. Specifically, (1) long term time series studies with continuous daily pollutant concentration and daily hospital admissions and deaths and, (2) personnel exposure and health impact studies need to be promoted.

References

Anon, Sri Lanka | Institute for Health Metrics and Evaluation. Available at: http://www.healthdata.org/sri-lanka [Accessed April 14, 2019].

Balakrishnan Kalpana et al., 2014. *Review 5: Population levels of household air pollution and exposures , WHO indoor air quality guidelines: household fuel combustion*, Geneva. Available at: http://www.who.int/indoorair/guidelines/hhfc/IAQ_HHFC_guidelines.pdf.

Brauer, M. et al., 2008. A Cohort Study of Traffic-Related Air Pollution Impacts on Birth Outcomes. *Environmental Health Perspectives*, 116(5), pp.680–686. Available at: https://ehp.niehs.nih.gov/doi/10.1289/ehp.10952 [Accessed April 14, 2019].

Bruce, N., Perez-Padilla, R. & Albalak, R., 2000. Indoor air pollution in developing countries: a major environmental and public health challenge. *Bulletin of the World Health Organization*, 78(9), pp.1078–92. Available at: http://www.ncbi.nlm.nih.gov/pubmed/11019457 [Accessed June 14, 2017].

Eze, I.C. et al., 2015. Association between Ambient Air Pollution and Diabetes Mellitus in Europe and North America: Systematic Review and Meta-Analysis. *Environmental Health Perspectives*, 123(5), pp.381–389. Available at: http://www.ncbi.nlm.nih.gov/pubmed/25625876 [Accessed April 14, 2019].

Hedley, A.J. et al., 2002. Cardiorespiratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: an intervention study. *Lancet (London, England)*, 360(9346), pp.1646–52. Available at: http://www.ncbi.nlm.nih.gov/pubmed/12457788 [Accessed April 14, 2019].

McCracken, J. et al., 2011. Intervention to Lower Household Wood Smoke Exposure in Guatemala Reduces ST-Segment Depression on Electrocardiograms. *Environmental Health Perspectives*, 119(11), pp.1562–1568. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21669557 [Accessed June 9, 2018].

Morici, G. et al., 2019. Environmental Conditions, Air Pollutants, and Airways. In *Exercise and Sports Pulmonology*. Cham: Springer International Publishing, pp. 209–221. Available at: http://link.springer.com/10.1007/978-3-030-05258-4_14 [Accessed April 14, 2019].

Nandasena, S., Wickremasinghe, A. & Sathiakumar, N., 2012. Air pollution and public health in developing countries: Is Sri Lanka different? *Journal of the College of Community Physicians of Sri Lanka*, 17(1), p.15. Available at: https://jccpsl.sljol.info/article/10.4038/jccpsl.v17i1.4932/ [Accessed April 15, 2018].

Nandasena, S., Wickremasinghe, A.R. & Sathiakumar, N., 2012. Biomass fuel use for cooking in Sri Lanka: analysis of data from national demographic health surveys. *American journal of industrial medicine*, 55(12), pp.1122–8. Available at: http://doi.wiley.com/10.1002/ajim.21023 [Accessed April 20, 2017].

Nandasena, S., Wickremasinghe, A.R. & Sathiakumar, N., 2013. Indoor air pollution and respiratory health of children in the developing world. *World Journal of Clinical Pediatrics*, 2(2), p.6. Available at: http://www.ncbi.nlm.nih.gov/pubmed/25254169 [Accessed April 19, 2017].

Nandasena, Y.L.S., Wickremasinghe, A.R. & Sathiakumar, N., 2010. Air pollution and health in Sri Lanka: a review of epidemiologic studies. *BMC public health*, 10, p.300.

Ren, C. & Tong, S., 2008. Health effects of ambient air pollution - Recent research development and contemporary methodological challenges. *Environmental Health: A Global Access Science Source*.

Renzi, M. et al., 2018. Air pollution and occurrence of type 2 diabetes in a large cohort study. *Environment International*, 112, pp.68–76. Available at:

http://www.ncbi.nlm.nih.gov/pubmed/29253730 [Accessed April 14, 2019].
Shah, P.S., Balkhair, T. & Knowledge Synthesis Group on Determinants of Preterm/LBW births, 2011. Air pollution and birth outcomes: A systematic review. *Environment International*, 37(2), pp.498–516. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21112090 [Accessed April 24, 2017].
WHO, 2006. *Air Quality Guidelines: Global Update 2005*,
WHO, 2000. *WORLD HEALTH ORGANISATION ORGANISATION MONDIALE DE LA SANTÉ WELTGESUNDHEITSORGANISATION ВСЕМИРНАЯ ОРГАНИЗАЦИЯ ЗДРАВООХРАНЕНИЯ Quantification of the Health Effects of Exposure to Air Pollution Report of a WHO Working Group*, Available at: http://www.euro.who.int/__data/assets/pdf_file/0011/112160/E74256.pdf [Accessed April 14, 2019].

Annexures

<u>Annexure 1</u>

AGENDA

Inception Workshop of the Project on Air Quality Assessment for Health and Environment Policies

Date | time September 12, 2018 | From 8.30 am to 4.00 pm
Organized by Ministry of Mahaweli Development & Environment

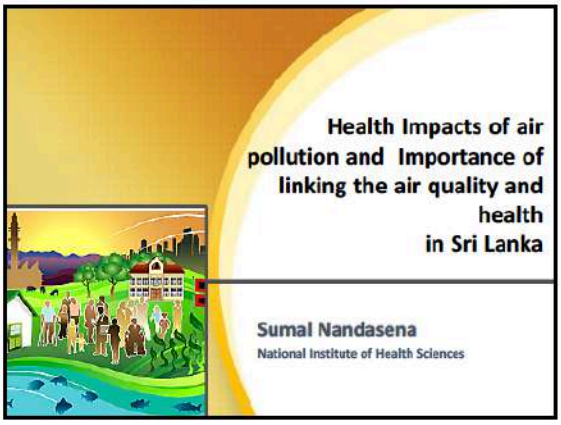
Objective

Mapping of stakeholders to contribute to the project (including identification of role in air quality and health), to discuss the details of the implementation of the project and to identify data to be collected for the air quality and health impact assessment.

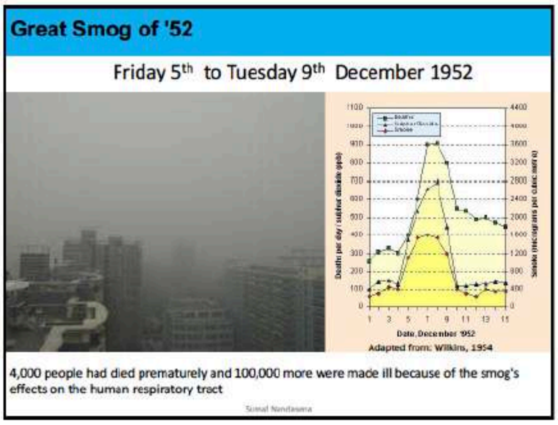
TIME	ITEM
08.30 AM – 09.00 AM	REGISTRATION
09.00 AM – 09.10 AM	WELCOME AND THE OBJECTIVES OF THE PROGRAM MR. SUGATH DARMAKEERTHI, DIRECTOR: AIR RESOURCE MANAGEMENT AND NATIONAL OZONE UNIT, MINISTRY OF MAHAWALI DEVELOPMENT AND ENVIRONMENT
09.10 AM – 09.30 AM	INTRODUCTION OF THE UNEP PROJECT ON AIR QUALITY ASSESSMENT FOR HEALTH AND ENVIRONMENT POLICIES IN AFRICA AND ASIA-PACIFIC MR. BERT FABIAN, REPRESENTATIVE, UNITED NATIONS ENVIRONMENT PROGRAMME
09.30 AM – 09.50 AM	AIR QUALITY MONITORING, MANAGEMENT POLICY DEVELOPMENT AND IDENTIFICATION OF DATA SOURCES MR. H D S PREMASIRI, SENIOR SCIENTIST, NATIONAL BUILDING RESEARCH ORGANIZATION
09.50 AM – 10.10 AM	HEALTH IMPACTS OF AIR POLLUTION IMPORTANCE OF LINKING THE AIR QUALITY AND HEALTH DR. SUMAL NANDASENA, CONSULTANT COMMUNITY PHYSICIAN, NATIONAL INSTITUTE OF HEALTH SCIENCES
10.10 AM – 10.25 AM	INTRODUCTION TO THE GROUP WORK 1. AIR QUALITY MANAGEMENT AND SOURCES OF AIR QUALITY IN SRI LANKA 2. METHOD OF ASCERTAINED THE DATA ON HEALTH OUTCOMES AND METHODS TO MINIMIZE THE OVERLAPPING 3. HOW DO AIR QUALITY AND HEALTH OUTCOMES COULD BE LINKED IN SRI LANKA

TIME		ITEM
10.25 AM	– 10. 45 AM	COFFEE BREAK AND NETWORKING
10.45 AM	– 12.45 PM	GROUP WORK
12.45 PM	– 01.45 PM	LUNCH
01.45 PM	– 03.15 PM	GROUP PRESENTATIONS
03.15 PM	– 03.45 PM	DISCUSSION
03.45 PM	– 04.00 PM	VOTE OF THANKS & EVENING REFRESHMENT

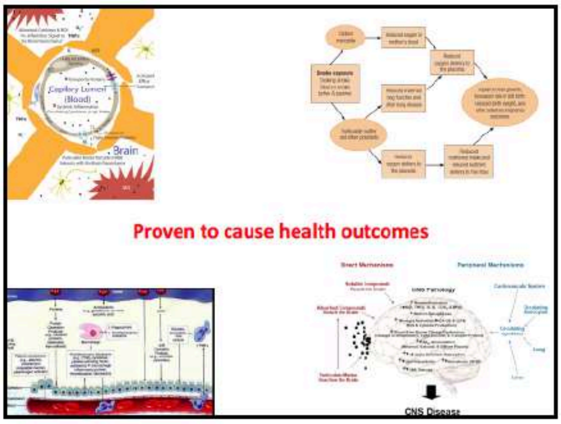
Annexure 2



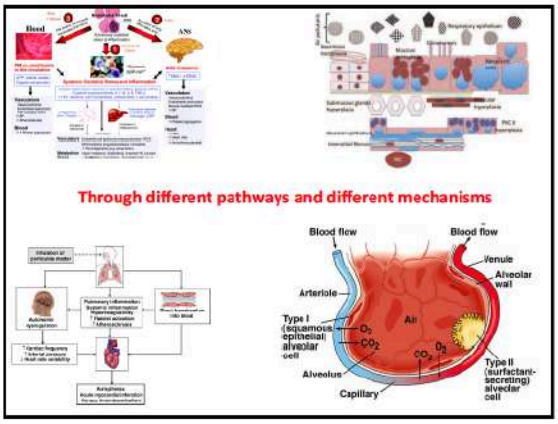
Health Impacts of air pollution and Importance of linking the air quality and health in Sri Lanka
Sumal Nandasena
National Institute of Health Sciences



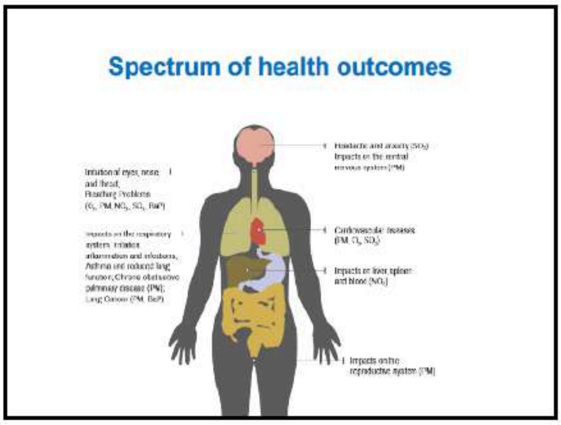
Great Smog of '52
Friday 5th to Tuesday 9th December 1952
Date, December 1952
Adapted from: Wilkins, 1954
4,000 people had died prematurely and 100,000 more were made ill because of the smog's effects on the human respiratory tract



Proven to cause health outcomes
CNS Disease

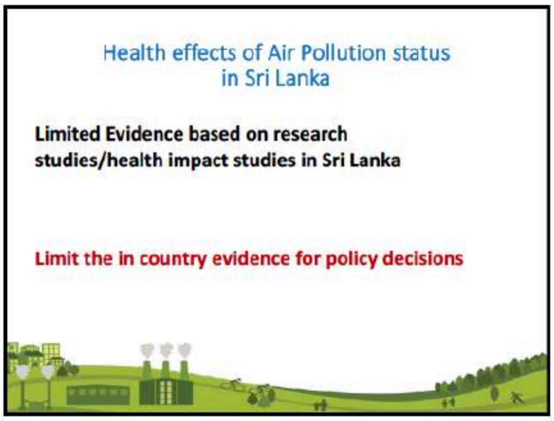


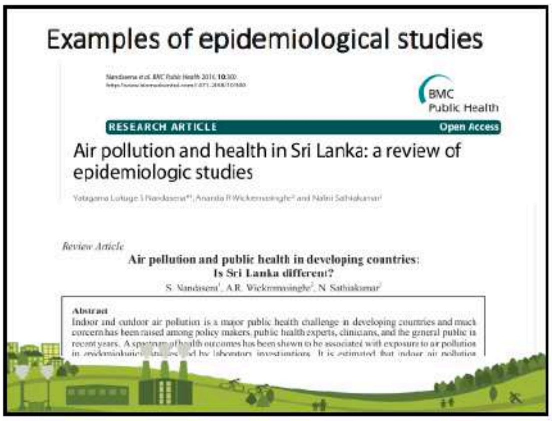
Through different pathways and different mechanisms
Blood flow
Blood flow
Venule
Alveolar wall
Arteriole
Type I (squamous epithelial) alveolar cell
Air
Type II (surfactant-secreting) alveolar cell
Alveolus
Capillary

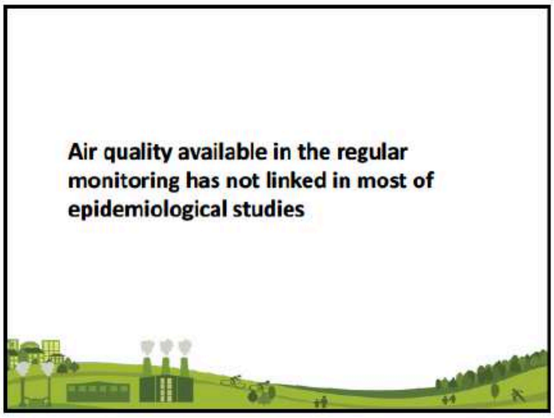


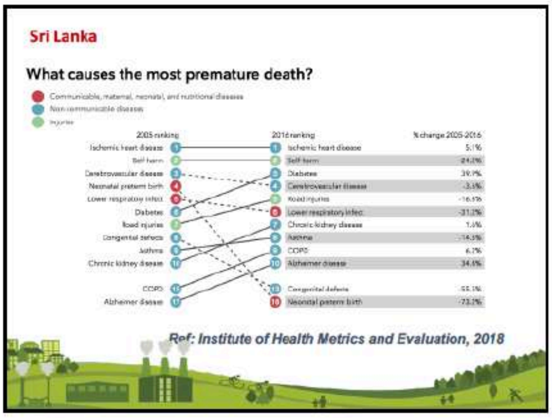
Spectrum of health outcomes

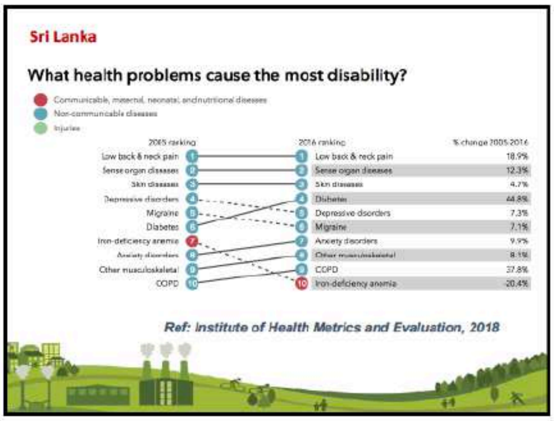
Air Pollution is strongly linked with SDG


Health effects of Air Pollution status in Sri Lanka
Limited Evidence based on research studies/health impact studies in Sri Lanka
Limit the in country evidence for policy decisions

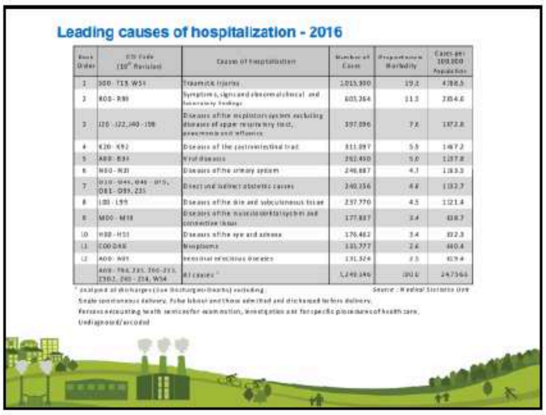

Examples of epidemiological studies
BMC Public Health
RESEARCH ARTICLE
Open Access
Air pollution and health in Sri Lanka: a review of epidemiologic studies
Review Article
Air pollution and public health in developing countries: Is Sri Lanka different?
Abstract
Indoor and outdoor air pollution is a major public health challenge in developing countries and much concern has been raised among policy makers, public health experts, clinicians, and the general public in recent years.

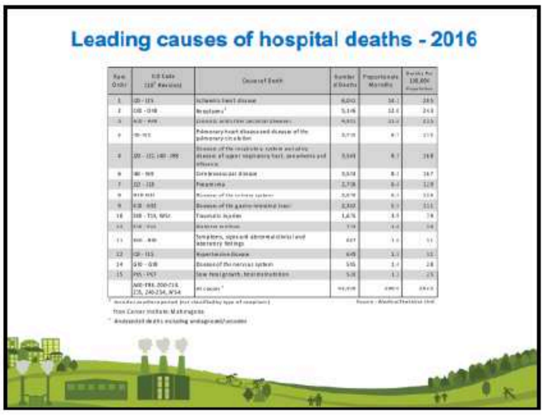

Air quality available in the regular monitoring has not linked in most of epidemiological studies


Sri Lanka
What causes the most premature death?
2005 ranking
2016 ranking
% change 2005-2016
Ischemic heart disease
Diabetes
Road injuries
Congenital defects
Asthma
Chronic kidney disease
COPD
Alzheimer disease
Cerebrovascular disease
Neonatal preterm birth
Lower respiratory infec
Chronic kidney disease
5.1%
39.7%
-3.5%
-31.2%
1.6%
6.7%
34.6%
-73.2%
Ref: Institute of Health Metrics and Evaluation, 2018

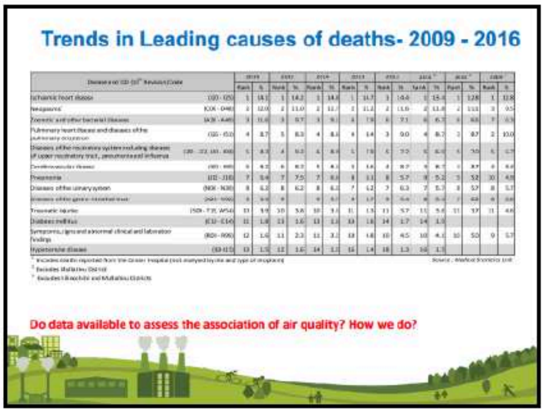

Sri Lanka
What health problems cause the most disability?
Communicable, maternal, neonatal, and nutritional diseases
Non-communicable diseases
Injuries
2005 ranking
2016 ranking
% change 2005-2016
Low back & neck pain
Sense organ diseases
Skin diseases
Depressive disorders
Migraine
Diabetes
Iron-deficiency anemia
Anxiety disorders
Other musculoskeletal
COPD
18.9%
12.3%
4.7%
44.8%
7.3%
7.1%
9.9%
8.1%
37.8%
-20.4%
Ref: Institute of Health Metrics and Evaluation, 2018

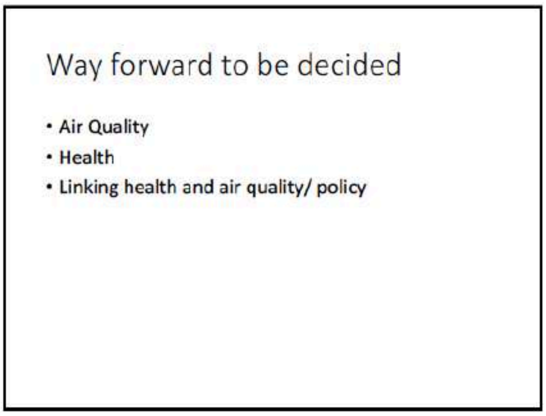

Sri Lanka
Key Risk factors to disability and death : 2016
High fasting plasma glucose
Dietary risks
High blood pressure
High body-mass index
Tobacco
Air pollution
Alcohol & drug use
High total cholesterol
Occupational risks
Impaired kidney function
Malnutrition

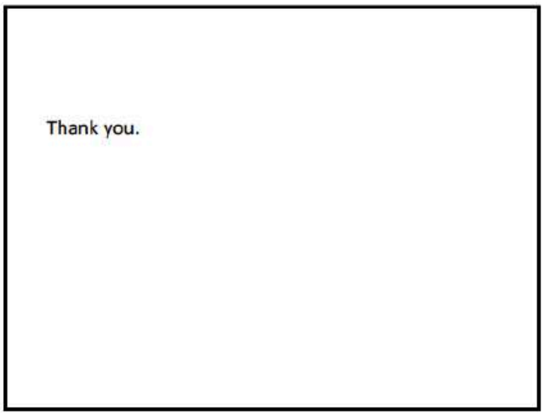

Leading causes of hospitalization - 2016


Leading causes of hospital deaths - 2016


Trends in hospitalizations – 2007 - 2016
Do data available to assess the association of air quality? How we do?


Trends in Leading causes of deaths- 2009 - 2016
Do data available to assess the association of air quality? How we do?


Way forward to be decided
• Air Quality
• Health
• Linking health and air quality/ policy


Thank you.

Annexure 3

Mid-year Population Estimates by District & Sex, 2013 - 2018

In Thousands

District	2013			2014			2015		
	Total	Male	Female	Total	Male	Female	Total	Male	Female
Sri Lanka	**20,585**	**9,966**	**10,619**	**20,778**	**10,059**	**10,719**	**20,970**	**10,153**	**10,817**
Colombo	2,339	1,148	1,191	2,353	1,155	1,198	2,367	1,161	1,206
Gampaha	2,324	1,126	1,198	2,339	1,133	1,206	2,355	1,141	1,214
Kalutara	1,233	597	636	1,242	601	641	1,252	606	646
Kandy	1,391	663	728	1,404	669	735	1,417	676	741
Matale	491	237	254	496	239	257	501	242	259
Nuwara-eliya	724	346	378	733	351	382	741	354	387
Galle	1,074	515	559	1,083	519	564	1,092	524	568
Matara	824	395	429	832	398	434	840	402	438
Hambantota	610	300	310	618	304	314	625	307	318
Jaffna	589	277	312	593	278	315	596	280	316
Mannar	101	51	50	102	51	51	103	52	51
Vavuniya	175	86	89	178	88	90	181	89	92
Mullaitivu	93	46	47	95	47	48	96	48	48
Kilinochchi	116	57	59	118	58	60	119	58	61
Batticaloa	531	253	278	535	255	280	541	258	283
Ampara	658	318	340	666	322	344	674	326	348
Trincomalee	385	190	195	391	193	198	396	196	200
Kurunegala	1,634	784	850	1,647	791	856	1,661	798	863
Puttalam	771	373	398	778	377	401	786	380	406
Anuradhapura	874	427	447	886	433	453	896	437	459
Polonnaruwa	411	203	208	416	206	210	422	209	213
Badulla	826	397	429	836	402	434	846	407	439
Monaragala	460	229	231	467	232	235	475	236	239
Ratnapura	1,102	543	559	1,114	549	565	1,125	555	570
Kegalle	849	405	444	856	408	448	863	411	452

Source: Registrar General's Department

Note : Mid-year Population estimates were calculated based on the Census of Population and Housing 2012.
District level figures are given on the basis of usual residence.

Annexure 4:

Data request letter from Ministry of Health

මහවැලි සංවර්ධන හා පරිසර අමාත්‍යාංශය
மகாவலி அபிவிருத்தி மற்றும் சுற்றாடல் அமைச்சு
Ministry of Mahaweli Development and Environment

"Sobadam Piyasa", No. 416/C/1, Robert Gunawardana Mawatha, Battaramulla, Sri Lanka.
Gen. Tel. +94-11-2034100
Secretary +94-11-2034121
Fax +94-11-2879945

My No 04/03/06/AQA/15/VOL II
Your No
Date 2018.11.26

Chief med. stat unit
pl provide necy data to Dr Sumal Nandasena

Additional Secretary
Medical Services
Ministry of Health, Nutrition and Indigenous Medicine

Health Data request for Air Quality and Health Assessment

The Ministry of Mahaweli Development and Environment with the financial and technical support from the United Nations Environment Programme planning to conduct a health impact of air pollution in Sri Lanka. The proposed health impact assessment is nationally important to generate evidence to revise, evaluate and develop environmental policies related to air pollution in Sri Lanka.

Proposed variables to request are attached here with. The data will not be published in view of identification of patients and hospitals (disaggregated). Dr. Sumal Nandasena, a consultant community physician from Ministry of Health will be member of the health impact assessment team and he will involve in handling the health-related data. I would be grateful, if you could provide the data to him in order to carry out the said health impact assessment.

Add/Se/(MS)
2018/12/4

If you need any clarification please do not hesitate to contact Mr Sugath Dharmakeerthi, Director of Air Resource Management and National Ozone Unit through 011-2034215, fax 011-2879974 or Email-airmac2016@gmail.com

Your Cooperation in this regard is highly appreciated.

Dr. S...
Consultant in Medical Administration
Additional Secretary (Medical Services)
Ministry of Health, Nutrition & Indigenous Medicine
"Suwasiripaya"
385, Rev. Baddegama Wimalawansa Thero Mawatha
Colombo 10.

D. Jeevanadan
Additional Secretary (Natural Resources)
For Secretary

CC. 1. Director, Medical Statistics Unit, Ministry of Health
2. Dr. Sumal Nandasena, Consultant Community Physician, Ministry of Health

"This great earth and the flora on it equally belong to the man and the birds flying in the sky, the quadrupeds and all creatures living on earth"

Annexure 5:

Study title	Main assessment/objective	Statistical method
Effect of Air Pollution on Hospital Admissions of Respiratory, Dermatological, Ophthalmic Diseases in a Coastal City, China	effect of air quality on pediatric hospital admissions for respiratory disease, dermatological illness and ophthalmic diseases	Generalized additive model
Chronic obstructive pulmonary disease exacerbations and progression in relation to ambient air pollutants exposure	PM_{10} or SO_2 concentration and number of exacerbations or hospital stay	Linear and non-linear regression analyses.
Acute effects of fine particulate matter ($PM_{2.5}$) on hospital admissions for cardiovascular disease in Beijing, China: a time-series study.	association between exposure to $PM_{2.5}$ and hospitalizations for total and cause-specific CVD, including coronary heart disease (CHD), atrial fibrillation (AF), and heart failure (HF) after controlling for the season,	A generalized additive model using a quasi-Poisson distribution
Fine particulate air pollution and adult hospital admissions in 200 Chinese cities: a time-series analysis.	city-specific associations of PM2.5 concentrations with hospital admissions.	Generalized additive models with quasi-Poisson regression
Impact of air pollution on hospital admissions with a focus on respiratory diseases: a time-series multi-city analysis.	air pollutants on hospitalizations	Correlation analysis and distributed lag nonlinear models
Association between ambient air pollution and hospital admission for epilepsy in Eastern China.	air pollutants and hospital admission, with temperature and relative humidity adjusted using the natural spline	conditional Poisson regression model
Effect of Air Pollution on Hospital Admissions of Respiratory, Dermatological, Ophthalmic Diseases in a Coastal City, China	General calculations were performed in SPSS. and the results were expressed as the percent change in daily hospital admissions for IQR change in pollutant concentration.	GAM models were developed using R statistical software with" mgcv" package