uOttawa

L'Université canadienne
Canada's university

FACULTÉ DES ÉTUDES SUPÉRIEURES ET POSTOCTORALES

uOttawa

L'Université canadienne
Canada's university

FACULTY OF GRADUATE AND POSDOCTORAL STUDIES

Jessica Evans
AUTEUR DE LA THÈSE / AUTHOR OF THESIS

M.Sc. (Epidemiology)
GRADE / DEGREE

Department of Epidemiology and Community Medicine
FACULTÉ, ÉCOLE, DÉPARTEMENT / FACULTY, SCHOOL, DEPARTMENT

Use of Satellite Imagery to Estimate Global Mortality Attributable to Fine Particulate Air Pollution

TITRE DE LA THÈSE / TITLE OF THESIS

Daniel Krewski
DIRECTEUR (DIRECTRICE) DE LA THÈSE / THESIS SUPERVISOR

Nicholas Birkett
CO-DIRECTEUR (CO-DIRECTRICE) DE LA THÈSE / THESIS CO-SUPERVISOR

Dave Stieb

Robert Dales

Gary W. Slater
Le Doyen de la Faculté des études supérieures et postdoctorales / Dean of the Faculty of Graduate and Postdoctoral Studies

USE OF SATELLITE IMAGERY TO ESTIMATE GLOBAL MORTALITY ATTRIBUTABLE TO FINE PARTICULATE AIR POLLUTION

Jessica Evans

Thesis submitted to the Faculty of Graduate and Postdoctoral Studies in partial fulfilment of the requirements for the MSc degree in Epidemiology

Department of Epidemiology and Community Medicine
Faculty of Medicine
University of Ottawa

Your file Votre référence
ISBN: 978-0-494-73855-9
Our file Notre référence
ISBN: 978-0-494-73855-9

ABSTRACT

Background: Studies assessing the effects of air pollution on health have traditionally relied upon ground-monitoring stations to measure ambient concentrations. Use of satellite derived air pollution measures poses the advantage of providing global coverage.

Objective: To undertake a global assessment of mortality associated with chronic exposure to fine particulate air pollution using remote sensory data.

Methods: Global $PM_{2.5}$ exposure levels were derived from MODIS and MISR satellite instruments. Relative risks and attributable fractions of mortality were modelled using previously developed concentration-response functions for the association between $PM_{2.5}$ and mortality.

Results: The global fraction of adult mortality attributable to the anthropogenic component of $PM_{2.5}$ was 4.5% (95% confidence interval: 2.9-6.0) for cardiopulmonary disease, 5.6% (2.5-8.3) for lung cancer, and 8.2% (5.6-10.4) for ischemic heart disease.

Conclusion: This study demonstrated that it is feasible to use satellite derived pollution concentrations in a global assessment of mortality and air pollution.

ACKNOWLEDGEMENTS

I would like to thank Aaron van Donkelaar and Randall Martin for providing global satellite derived fine particulate matter concentrations and related content expertise. I would also like to extend a special thanks to Rick Burnett for his role in methodology development and for his support throughout this thesis. Finally, I would thank to Daniel Rainham, as well as my supervisor Daniel Krewski, and my co-supervisor Nicholas Birkett for their ongoing support and advice.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Particulate matter (PM), a mixture of organic, inorganic, and biological materials, consists of tiny solid or liquid particles suspended in the atmosphere. Although these particles are generated primarily from anthropogenic activities such as fuel combustion or mechanical grinding, they can also arise from natural sources such as volcanoes, wind blown dust, and sea salt.(1) The tendency is for larger particles to be derived mainly from crustal materials, while smaller particles are more likely the result of fossil fuel combustion.(2) For this reason, the specific composition of PM can vary dramatically by location, as the sources of PM vary according to local industry and geophysical properties. Fine-particulate matter ($PM_{2.5}$) is the term for particles with median aerodynamic diameter equal to or below 2.5μm, while coarse particulate matter (PM_{10}) has a median diameter greater than 2.5μm and less than 10μm.

Based on a systematic review of health effects related to PM, it was concluded that fine particulate matter is of greater concern than the coarser fraction of PM (3), a finding that could be due to $PM_{2.5}$ components having greater toxicity as well as being more prone to deep inhalation into the lungs.(4)

While both short-term and long-term effects have been observed in relation to PM, the magnitude of the association between mortality and long-term exposure to PM is thought to be greater than that observed with short-term exposure, thus, long-term exposure may be more important from a public health perspective.(5,6)

Traditionally, epidemiological studies assessing the effects of air pollution on population health have relied on fixed-site ground-monitoring stations to measure concentrations of air pollution.(2,5,7-9) Fixed-site monitors produce point air pollution exposure estimates which are applied to surrounding populations. However, the distances between the sites of exposure assessment and the populations of interest can be substantial, and exposure misclassification is a limiting factor of these studies, with there being the potential for biased estimates of the associations between air pollution and health outcomes. Even when complex networks of stationary monitors are used to assess population exposure to air pollution, there are often gaps where portions of the population are not covered by the scope of these monitors; and, these gaps could overlap with pollution hot spots.

The evolution of air quality modelling techniques has resulted in a methodology for estimating air pollution when there are no monitors in close proximity. These models, such as the World Banks's Global Model of Ambient Particulates (GMAPS), are used to estimate pollution gradients between fixed-site monitors, with input factors such as fuel mix, level of economic development, demographics and weather.(10) Unfortunately, the inventories for these variables are not always easily maintained or accurately estimated.(11)

The use of satellite sensors to assess air quality has advanced rapidly over the last decade,(12) and continues to be a developing area. Measuring aerosols such as PM in the atmosphere is challenging since they are unevenly distributed according to space and time, accumulating at sources and sinks due to their short life spans.(13) This characteristic of aerosols limits the effectiveness of fixed site ground-based PM monitors to capture large-scale, regional and global PM distributions.(14,15) Conversely, satellite sensors can account for spatial variability and long-range transport of air pollution, and thus provide global coverage of aerosols by measuring air pollution concentration gradients between stationary monitors, as well as in regions that lack ground monitoring capabilities all together.(16) For this reason, remote sensing has the potential to provide important information in global assessments of air pollution.

Although use of satellite sensing to monitor air quality is uncommon (16), it is a developing area. The current study has used air pollution data generated from two satellite sensors, the Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging Spectroradiometer (MISR), to assess global mortality attributable to fine particulate air pollution. To the author's knowledge, this is the first study to employ satellite measures in a global assessment of mortality attributable to air pollution.

2.0 REVIEW – USE of SATELLITE SENSORS to MEASURE $PM_{2.5}$

2.1 Background

Concentrations of various air pollutants including nitrogen dioxide, sulphur dioxide, carbon monoxide, formaldehyde, ozone, as well as aerosols can be measured via remote sensing instruments. (12,14,17) To clarify, while particulate matter refers to tiny solid or liquid particles in gas, aerosol refers to the combination of these particles and gas. Levels of particulate matter can be derived from measures of atmospheric aerosol.

Aerosols exist primarily in the lowest atmospheric layer, the troposphere, and while aerosols can be located in the second major atmospheric layer, the stratosphere, their concentrations are very small.(18) The troposphere is composed of two layers, the lower of which is termed the planetary boundary layer (PBL). The air quality in the PBL is of most interest from a public health perspective. Satellite sensors measure properties of tropospheric aerosol; and, of particular interest, they are used to determine the aerosol optical depth (AOD), a measure of light extinction by aerosol in the atmospheric column.(19) Aerosol optical depth is also referred to as aerosol optical thickness (AOT) in the literature. The atmospheric column is the vertical depth of the atmosphere between the ground and the sensor.(16,20) Ground-level PM concentrations are estimated from satellite AOD measurements through use of chemical transport models to provide information on the vertical structure of the atmosphere.(12)

Solar radiation is reflected by the atmosphere at various wavelengths, angles and polarizations, and this information can be captured by satellite sensors to determine air quality. Satellite sensors observe these radiances at various wavelengths, which vary by instrument.(15) Aerosol retrieval algorithms, which are based on optical properties of the atmosphere and surface, are used to generate measurements of AOD.(18) In order to accelerate the process of calculating AOD, the algorithms rely on input from lookup tables of predetermined atmospheric properties (21,22). Radiance properties are very different for land compared to ocean, with water reflection being relatively low and homogeneous.(23)

Thus, AOD algorithms are unique not only to the instrument, but they also differ depending on surface type, for example land versus ocean.

Satellites with instruments that measure air pollutants in the lower troposphere fly near-polar, sun-synchronous, low Earth orbits.(12) The National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS) consists of a series of low, polar orbiting satellites with sensors designed for the long-term global observation of the surface, biosphere, solid Earth, atmosphere, and oceans. Air quality data from the Earth Observing System's (EOS) satellite sensors are provided through Distributed Active Archive Centers (DAACs), namely the NASA Goddard Space Flight Center and the NASA Langley Research Center. Two instruments onboard the EOS Terra satellite, MISR and MODIS, were designed specifically for the purpose of retrieving aerosol data.(18) MODIS and MISR aerosol data are available free of charge on the internet. Through use of specific software, the data can be processed by researchers to develop aerosol optical thickness and ultimately PM estimates.

2.2 Select Overview of Satellite Sensors that Measure Atmospheric Aerosols

Use of satellite sensors to measure tropospheric trace gases began in 1978 with the Total Ozone Mapping Spectroradiometer (TOMS).(12) TOMS was designed to provide daily global information on ozone (O_3), but can measure aerosols under specific conditions using two ultraviolet light channels.(16,20) Although TOMS can be used to track large scale global aerosol events,(18) its low sensitivity to aerosols near the ground is a limiting factor for its use in air quality monitoring.(24)

The Sea-viewing Wide Field-of-view Sensor (SeaWiFS), designed to monitor daily ocean true colour and biological productivity, is another sensor that can measure atmospheric aerosols.(16) A major limiting factor for using SeaWiFS to measure aerosols is its lack of onboard calibration.(18)

The first satellite sensor *designed* specifically to measure aerosols was the Polarizing and Directionality of the Earth's Reflectances (POLDER), and it could detect fine aerosols over land using several spectral channels in the range of 0.44-0.86mm.(20) Unfortunately, data collection was terminated after 8 months when its satellite, ADEOS, malfunctioned.(18)

The EOS Terra satellite has 3 instruments on board that are used to estimate air quality at the Earth's surface: the Multi-angle Imaging SpectroRadiometer (MISR), the MODerate Resolution Imaging Spectroradiometer (MODIS), and the Measurement of Pollution in the Troposphere (MOPITT). MOPITT measures carbon monoxide, while MISR and MODIS were purposely designed to measure aerosol properties, and can provide information on aerosol optical depth (AOD).(12) The MISR and MODIS AOD datasets have the longest period of observation compared to other AOD datasets. Three other instruments measure AOD: Ozone Monitoring Instrument (OMI) on the Aura satellite (launched 2004); Parasol on the Parasol satellite (launched 2004); and, CALIOP on the CALIPSO satellite (launched 2006).(12)

The current research is based on aerosol measurements from the MISR and MODIS sensors on board the EOS Terra satellite.

2.3 Moderate Resolution Imaging Spectroradiometer (MODIS)

Located on NASA's EOS Terra and Aqua satellites, MODIS on Terra was launched in December of 1999 and began acquiring daily global measurements since February of 2000.(25) MODIS on Aqua was launched August 2002 and has an overpass time 3 hours behind MODIS-Terra.(16) AOD retrievals from MODIS-Terra and MODIS-Aqua have been compared, and were found to have similar accuracies.(26)

One feature of the MODIS instrument is its use of multiple spectral bands. MODIS provides daily global aerosol measurements using 36 spectral bands, which is considerable compared to most sensors which use between 4 and 8 channels.(16) Spatially, MODIS resolution ranges from 250m to 1km, and temporally, provides global coverage every 1 to 2 days.(15,16) Another feature of the instrument is high calibration accuracy with its many onboard calibrators. (18)(18,27)

MODIS aerosol algorithms were initially developed by Kaufman et al. (1997) and Tanré et al. (1997).(28,29) These algorithms have been updated over time with minor modifications to deal with factors which have been found to affect accurate AOT retrieval, for instance clouds and inland water features.(16,25,30,31) There are 2 MODIS aerosol algorithms, one for land and one for ocean.(32) MODIS uses a wider spectral range over the ocean (0.47-2.1mm) in order to distinguish fine pollution from sea-salt and dust, while over land it uses the 2.1mm channel to assess surface cover and reflectance while deriving AOT.(20)

MODIS retrieves aerosol loading and the fraction of fine mode particles.(13) In addition to providing AOD measurements, this instrument also observes land cover as well as meteorological factors such as land surface temperature, water vapour, and atmospheric profiles, which can be used to inform air quality models.(16)

Traditionally, one limitation of the MODIS instrument is its difficulty distinguishing aerosol from highly reflective surfaces such as clouds, water, snow/ice, and desert areas.(24) As a result, MODIS AOD retrieval over these surfaces has been restricted.

2.4 Multi-angle Imaging Spectroradiometer (MISR)

MISR is located on the Terra satellite platform. One of the most recent major advancements in remote sensing was the development multiple angles to measure aerosol properties.(18,27) MISR is able to view the atmosphere from various angles using 9 cameras in various view directions: down, forward and behind the spacecraft track.(16,18)

Spatially, MISR has a resolution of 275m to 1.1km, using 4 spectral channels to view the Earth's atmosphere.(12,18) MISR has a relatively large temporal resolution and it views the earth every 7-9 days.(24)

The angles of light reflected by the surface are different from that of the atmosphere, and MISR employs multiple view angles to separate surface reflectance from aerosol reflectance.(20,33) MISR is therefore not restricted by land surface reflectance, and can retrieve AOT over bright surfaces. Another advantage of MISR is its onboard calibration hardware that is detector-based to provide high accuracy data.(18,34)

Limitations of MISR include its inability to provide daily coverage, such that it cannot be used for daily forecasting,(24) as well as its lack of thermal channels for cloud screening.(18)

2.5 MODIS versus MISR

The MISR and MODIS sensors, though similar in many ways, also have unique strengths. Table 2.1 outlines a brief comparison of the main attributes of each instrument.

Table 2.1 Comparison of MODIS and MISR features

	MODIS	**MISR**
Satellite	Terra, Aqua	Terra
Spectral Channels	36	4
Multiple Angles	No	Yes
Spatial Resolution	275m-1km	275m-1.1km
Temporal Resolution	1-2 days	7-9 days
Calibration	Onboard	Onboard

Several studies have compared aerosol measurements derived from MODIS and MISR. In a comparison of MISR and MODIS aerosol optical depth (AOD) collected for 3 months in 2002, it was found that for all land types, MODIS produced measurements that were 10-35% larger as compared to MISR estimates.(35) However, when high reflection surfaces such as coastal sites with subpixel water contamination and desert areas were excluded from the comparison, the differences decreased since MODIS estimates were biased high over these surfaces.(35) In this particular study, the authors attributed the discrepancies between MISR and MODIS AOD measurements to differences in calibration or aerosol retrieval algorithms. In another study comparing MISR and MODIS AOD measurements for mainland Southeast Asia, MODIS was found to be consistently higher than MISR, with the differences being spatially clustered and having a strong negative relationship with MODIS AOD.(36) Finally, MISR and MODIS AOD were compared to ground-level measures of AOD for 2001-2005 during summer and winter months, and MISR was found to perform better than MODIS during both seasons.(37) MODIS overestimated AOD in summer while both MODIS and MISR underestimated AOD in the winter months.(37) MISR's better performance was attributed to its multiple viewing angles such that it can retrieve aerosol information from a variety of terrains, including reflective surfaces.(37) Overall, MISR yields an average AOT measurement accuracy of more than 0.05 ± 20% when compared with ground-level aerosol measurements, while that of MODIS is 0.05 ± 15%.(12)

Aerosol pollution measurements obtained from MODIS and MISR have also been compared. Liu et al (2007) compared $PM_{2.5}$ derived from MODIS versus MISR in the St. Louis, U.S. and surrounding area. It was reported that while both models underestimated $PM_{2.5}$ concentrations as compared to $PM_{2.5}$ derived from ground-level monitors, the MISR model explained slightly more of the variability in $PM_{2.5}$ concentrations as compared to the MODIS model, 62% versus 51% respectively.(38)

The variations in instrumental characteristics such as the number of spectral channels, use of multiple angles, temporal resolution, calibration methods, as well as the algorithms used to retrieve aerosols and generate $PM_{2.5}$ from AOD are potentially collectively contributing to similar but unique MODIS and MISR aerosol and particulate matter concentration estimates. Since these instruments are located on the same platform, and cover geographical areas which at times can overlap, the argument can be made for combining the data from both instruments to take advantage each sensor's strengths, while minimizing their weaknesses. For example, MISR is less capable of filling the gaps between sensors as is MODIS since it has a relatively narrow swath and long repeat-cycle; however, unlike MODIS, MISR can detect aerosols over varying terrain reflectivity. (39)

2.6 Applications for Satellite Imaging in Air Pollution Monitoring

Satellite sensors can supplement ground-based monitors when measuring surface emissions including natural aerosol episodes, forecasting air quality events, characterizing transboundary pollution, and assessing the impacts of air pollution on human health. Examples of these applications are discussed in more detail below.

2.6.1 Measuring Surface Emissions

A major application of satellite sensors is in estimating surface emissions.(12) It has been demonstrated that the integration of satellite data with ground-based data in back trajectory analyses for the days leading up to a known $PM_{2.5}$ event can be used to identify sources of pollutants, whether they be local or from another region.(19)

The most commonly reported use of satellite data is to study specific events, particularly natural events such as fires and dust storms.(16) Satellite sensors have been used to measure the impact of dust storms and fire emissions on air quality in Asia, North America, and Africa; and, through fusion of satellite imagery, surface monitors, biomass density maps, and model results, aerosol characterizations were greatly enhanced.(40-42)

2.6.2 Forecasting Air Quality

Use of satellite sensors to forecast air quality is increasingly being explored as the Continuous Air quality Monitoring (CAM) stations used for air quality forecasting are expensive to install and maintain, and substitution in part with satellite-based forecasting could be a means to save costs.(43)

Infusing satellite Data into Environmental Applications (IDEA) was developed by the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Environmental Protection Agency (EPA). IDEA is an effort to improve forecaster knowledge of continental distribution and transport of particulate matter across North America and involves combining MODIS aerosol measurements with hourly surface measurements and wildfire locations.(24) Currently, the

IDEA forecast model is being used in Texas to generate real-time air quality forecasts from AOD.(30)

2.6.3 Characterizing Transboundary Pollution

Unlike ground-based monitors, satellite sensors measure air pollution at a global level, and can be used beneficially to measure global transboundary transportation of pollutants. van Donkelaar et al. (2008) used a combination of satellite sensory data (including MISR and MODIS AOD), aircraft, and ground-based measurements to assess long-range transport of East Asian emissions to North America. It was estimated that annual Chinese sulphur emissions have grown annually by 6.2 to 9.6% based on MISR and MODIS respectively, and that 56% of measured sulphate over BC is due to East Asian sources.(44)

2.6.4 Assessing the Effects of Air Pollution on Health

There are very few studies that employ air pollution measures derived from satellite imagery in human health impact assessments. Hu et al. (2009) assessed the association between ischemic heart disease mortality and AOD measured from remote sensing and found a significant positive correlation.(45) In another study by the same group, the association between satellite-derived $PM_{2.5}$ and coronary heart disease in the United States was assessed using a geographical weighting regression.(46) A spatial association was found such that as exposure to $PM_{2.5}$ increased, as did mortality due to chronic coronary heart disease.(46)

2.7 Validation of MODIS and MISR Derived Aerosol Pollution Measures

The validation of satellite derived aerosol pollution measures can be categorized as follows: correlating satellite derived AOD to ground-based sun photometer derived AOD; correlating satellite derived AOD to ground-based PM concentrations; and, correlating PM concentrations modelled from satellite derived AOD to ground-based PM concentrations. This section will show that despite the challenges and limitations of using satellite instruments to measure aerosol concentrations, satellite derived AOD and PM concentrations have been found to be well correlated with ground-level measures of AOD and PM concentrations under certain conditions.

2.7.1 The Aerosol Robotic Network

The AErosol RObotic NETwork (AERONET) is a global network of automatic ground-level sun photometers which gather and store data on aerosol optical depth and other aerosol properties.(47) Due to its high accuracy, AERONET data is the gold standard by which satellite derived AOD measurements are compared.(35,47) One limitation of using AERONET in validation activities is that although there are more than 100 globally situated AERONET sun photometer stations, there are many regions where these measurements are scarce such as East Asia, India, and Australia.(13)

2.7.2 Correlating Satellite Derived AOD to Ground-Based AOD Measures

Chu et al. (2002) were the first to derive and validate aerosol optical depth (AOD) measurements over land. Global comparisons of MODIS and AERONET derived AOD resulted in linear correlation coefficients of ~0.85 to 0.98, depending on the wavelength used to derive AOD.(25) When assessed at the country or continental levels, the correlations were generally higher than at a global scale, except when correlations were assessed at continental coastal zones where water reflection was high.(25) In another study by Chu et al. (2003), the global validation of MODIS versus AERONET derived AOD over a 2-year period resulted in strong linear correlation coefficients in the range of 0.82 to 0.91.(13) The correlation between MODIS AOD and sun photometer AOD varies by aerosol loading, such that under low aerosol loadings MODIS AOD is overestimated while under high aerosol loadings, MODIS AOD is underestimated.(32) Seasonal variations also affect MODIS-AERONET AOD correlations, with maximum correlations being observed in the spring, and minimum correlations being reported in autumn and winter for parts of Asia.(27)

Similar to MODIS, MISR AOD has been strongly correlated with AERONET AOD. Correlations between MISR AOD and AERONET AOD have been reported to be between 0.73 and 0.93 for various countries.(33,48,49) In these studies, correlations were stronger for the fine fraction versus the coarse fraction of AOD, as well as stronger for coastal versus dusty sites.(48,49)

As was previously discussed, due to its use of multiple angles, MISR unlike MODIS is capable of measuring AOD over reflective desert surfaces. The correlations between MISR and sun photometer AOD for several desert sites were found to be highly correlated, with reported coefficients of greater than 0.85.(50,51) Correlations were generally lower with the passage of dust fronts (50) and when spatial resolution was decreased from 52.8km to 17.6km.(51) These results indicate that MISR is a useful tool for measuring AOD over highly reflective desert surfaces.

When MODIS and MISR satellite measurements were combined to derive $PM_{2.5}$ concentrations along with use of a global chemical transport model, a strong correlation coefficient of 0.91 was reported when compared to ground-level measures of $PM_{2.5}$ concentrations for the same regions.(52) In this study, MODIS AOD was used over the ocean and MISR AOD was predominantly used over the land when deriving $PM_{2.5}$ concentrations.(52)

2.7.3 Correlating Satellite Derived AOD to Ground-Based PM Concentrations

As one would expect, aerosol optical depth (AOD) measures are correlated to particulate matter (PM) concentrations. The correlation for daily PM_{10} concentrations and daily averaged AERONET AOD over a 3 month period in Italy was strong, with a linear correlation coefficient of 0.82.(13) Satellite derived AOD is also correlated to ground-level PM concentrations, though the strength of the linear correlation is dependent upon several key covariates.

When MODIS AOD was compared with ground-based PM concentrations from the United States Environmental Protection Agency monitoring data for 6 months in 2002, moderate linear correlation coefficients of 0.43 and 0.40 were observed for daily and hourly $PM_{2.5}$ readings respectively.(53) Overall, linear correlation coefficients in this study varied by location, and were generally poorer in the western versus eastern United States.(53) A similar linear correlation was found for MISR AOD when regressed (simple linear) with $PM_{2.5}$ concentrations, where a correlation coefficient of 0.48 was reported.(11) A major limitation of these studies was the lack of adjustment for important covariates affecting the relationship between AOD and $PM_{2.5}$ such as the height the planetary boundary layer (PBL), relative humidity, and meteorological factors.(11,24,54,55)

Gupta et al. (2006) were among the first to assess the relationship between satellite derived AOD and $PM_{2.5}$ concentrations in a global context. MODIS AOD was compared to ground-based $PM_{2.5}$ concentrations in India, Australia, Hong Kong, Switzerland, and the United States.(15) The linear correlation coefficient between daily bin-averaged $PM_{2.5}$ concentrations and MODIS AOD was strong (r=0.96); and, a sensitivity analysis revealed that the correlations were highest for cloud free conditions, low PBL height, and low relative humidity.(15) Another study conducted in Europe noted the importance of the PBL height and relative humidity covariates such that when they adjusted for, the one year time-series AOD-PM correlations improved from 0.3 to 0.5 and 0.6 for PM_{10} and $PM_{2.5}$ respectively.(23) Local meteorological conditions, surface type, aerosol chemical composition were also listed as factors affecting the strength of correlations.(23)

In the previously discussed study by Gupta et al. (2006), $PM_{2.5}$ measurements were averaged over a longer time frame (bin-averaged approach), where 24-h mean $PM_{2.5}$ was divided into 11 bins of 5 $\mu g/m^3$, and AOD-PM correlation coefficients were higher compared to other studies that did not use this approach. Correspondingly, the Center for Space Research (CSR), reported that initial linear correlation coefficients between MODIS AOD observations and ground-level $PM_{2.5}$ improved from 0.4-0.5 to greater than 0.90 using the bin-averaged approach.(31) However, the CSR is primarily interested in using satellite AOD for air quality forecasting, and the bin-averaged approach does not validate the data for use in a real-time setting. Further investigation by the group revealed that pixels containing surface water, termed 'hot spots', were biasing AOD measurements; and, when they were removed, correlations between real-time MODIS AOD observations and ground-based $PM_{2.5}$ were 0.9.(31) The CSR and NASA subsequently modified the MODIS aerosol retrieval algorithm to eliminate the 'hot spots' created by the inland water surfaces.(30)

2.7.4 Correlating Satellite Derived to Ground-Based PM Concentrations

Surface-level $PM_{2.5}$ concentrations were estimated for the United States using MISR AOD in conjunction with a global atmospheric chemistry model(49), and strong correlations were found between MISR $PM_{2.5}$ concentrations and surface-level $PM_{2.5}$ concentrations, r=0.78 to 0.81.(56) These correlations represent a significant improvement as compared to when atmospheric chemistry remains unaccounted for.(56)

In another study, $PM_{2.5}$ concentrations obtained from MODIS and MISR in conjunction with a global atmospheric chemical transport model were compared with surface $PM_{2.5}$ measurements in Canada and the United States. Correlations were moderate to strong with linear coefficients of 0.58 for MISR and 0.69 for MODIS.(57) The study also concluded that the relative vertical profile of aerosol extinction is the most important factor affecting the spatial relationship between satellite and surface $PM_{2.5}$ measurements. (57)
In a unique analysis, the potential sampling bias arising from satellite PM measurements being derived only under cloud-free conditions was assessed. Despite MODIS AOD data being available for less than 50% of the time compared to ground-based PM measurements, the mean differences between the two data sources was less than $2\mu g/m^3$ for both month and year time scales.(58) Ultimately, the study showed that low sampling from satellites due to cloud cover and other non-retrieval conditions such a surface-type does not hinder long-term $PM_{2.5}$ data generation from satellite measurements.

2.8 Summary

Use of satellite instruments to measure air pollution is a rapidly developing area, which can potentially offer unique advantages over traditional fixed-site monitors, as well as air pollution modelling techniques, particularly in a global context. The global coverage of air pollution provided by satellite instruments is valuable in locations where fixed-site monitors do not exist, and in addition, can supplement air pollution modelling activities.

The applicability of satellite derived particulate air pollution measures has traditionally been constrained by several limitations of this technology. These limitations will be discussed in the context of this study, such that long-term $PM_{2.5}$ exposure is of interest. One constraint of satellite AOD retrieval is its restriction to cloud-free conditions. Aerosol retrievals are put through cloud-screening tests, and if pixels are contaminated by clouds, they are eliminated from the retrieval process.(22) However, despite cloud-prone regions having less AOD data available to estimate exposure levels to PM, low sampling due to cloud cover may not hinder long-term $PM_{2.5}$ data generation from satellite measurements. (58)

Another limitation is that for any given region, AOD is only measured once a day at satellite overpass, whereas the true exposure period of interest is the full 24-hours in a day. Indeed, linear correlation coefficients were lower for daily and hourly time frames (11,53); however, when the time frames were increased using an averaging approach, linear correlation coefficients increased substantially and were reported to be strong.(15,31) Thus, satellite derived measures of aerosol pollution appear to be more valid for long-term assessments as opposed to forecasting and real-time evaluation of air pollution levels.

Finally, since AOD is the columnar aerosol loading from the surface to the top of the atmosphere, if PM is not actually found at ground level, or is distributed unevenly throughout the vertical column, the AOD will be poorly correlated with PM concentration. (24,59) However, even when aerosol distribution is not homogenous in the vertical column, by accounting for such factors as the height of the planetary boundary layer and the relative vertical profile of aerosol extinction; aerosol chemical composition; relative humidity; and, meteorological variables when deriving measures of particulate matter concentrations, the correlation between satellite and ground-based aerosol pollution measures can be greatly improved.(11,23,24,54,55,57)

Despite the challenges of deriving particulate air pollution measures from satellite sensors, satellite derived aerosol pollution measures have been found to be well correlated with ground-level aerosol pollution measures under certain conditions.(13,15,25,31,33,45,46,48-52,56,57) The $PM_{2.5}$ estimates employed in this work were derived by accounting for covariates that affect the correlation between satellite and ground-level air pollution estimates. In addition, Terra MISR and MODIS AOD data were combined to produce $PM_{2.5}$

estimates, which is thought to yield better $PM_{2.5}$ estimates since the instruments complement each other temporally and spatially, and MISR offers higher accuracy while MODIS provides better coverage.(38) The methods used to derive the $PM_{2.5}$ estimates in this work, and their correlation with ground-level measurements will be discussed in the methods section.

3.0 REVIEW – LONG-TERM $PM_{2.5}$ EXPOSURE and MORTALITY

3.1 Background

The association between mortality and ambient $PM_{2.5}$ exposure is typically reported by two overlapping exposure classifications: acute and chronic. As the current work aimed to assess mortality attributable to long-term $PM_{2.5}$ exposure, the following section of the review focuses on studies examining the health effects of chronic $PM_{2.5}$ exposure. Similarly, this section of the review will focus on reporting associations for the four air pollution causes of mortality assessed in this work: all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease.

In December of 2009, the U.S. Environmental Protection Agency (EPA) released the final Integrated Science Assessment (ISA) for particulate matter as part of the Agency's periodic review of the national ambient air quality standards (NAAQS) for PM.(60) Specifically, this comprehensive report reviewed all epidemiological and toxicological evidence available to date on the relationship between health effects and long-term $PM_{2.5}$ exposure. It was concluded that the evidence is sufficient to infer a causal relationship between long-term $PM_{2.5}$ exposure and cardiovascular effects, respiratory effects, and lung cancer mortality.(60)

There have been several long-term cohort studies assessing the association between $PM_{2.5}$ exposure and mortality. The following segment of the review will predominantly consist of summarizing these epidemiological studies, and will to a smaller extent report on previous global assessments of air pollution and mortality.

3.2 Long-term studies of $PM_{2.5}$ and mortality

3.2.1 Harvard Six Cities Study

The Harvard Six Cities study, or the Six Cities study, is a long-term, prospective cohort study designed to evaluate the health effects of exposure to various airborne pollutants. The original Harvard Six Cities Study followed 8,096 individuals in six U.S. cities over a 15-year period (1974-1989) and reported a significant association between all-cause and cardiovascular mortalities in relation to $PM_{2.5}$, PM_{10}, and sulfates.(2)

An extended analysis of this cohort was performed with additional follow-up from 1990 to 1998 which captured an additional 1368 deaths.(61) Significant increases in all cause and cardiovascular disease mortality were reported in association with long-term exposure to $PM_{2.5}$, based on data from the two periods.(61) An overall decrease of 27% (RR=0.73 [95% CI: 0.57-0.95] per 10 μg/m^3 $PM_{2.5}$) in the risk of all cause mortality was reported as $PM_{2.5}$ concentrations declined over time.(61)

3.2.2 American Cancer Society (ACS) Cohort

In 1982, the American Cancer Society (ACS) initiated a prospective cohort study and enrolled 1.2 million adults 30 years of age and older who were members of households with at least one individual 45 years of age or older. Participants completed a confidential questionnaire that included demographic, smoking history, alcohol use, diet, and education information. In the original assessment, mortality was followed-up in 550,000 individuals from 151 cities in the U.S. over a 7-year period, and air pollution measures were obtained from 1979 to 1983.(8) Significant increases in risk for all cause and cardiopulmonary disease mortality were reported in relation to $PM_{2.5}$.(8)

When the original study was extended to 16-years of follow-up, similar results were reported where each 10ug/m^3 elevation in $PM_{2.5}$ was associated with a 6% and 9% increased risk of all-cause and cardiopulmonary disease mortality, and in addition, a 14% increased risk of lung cancer mortality was reported.(9) These significant increases in risk were observed when air pollution was modelled from two different periods, 1979-1983 and 1999-2000. In a further analysis of this extended follow-up data, Pope et al. (2004) reported positive associations with mortality due to all cardiovascular diseases (RR=1.12 [95%CI: 1.08-1.15] per 10 μg/m3 $PM_{2.5}$). Additionally, significant increases in ischemic heart disease (RR=1.18 [95% CI: 1.14-1.23] per 10 μg/m3 $PM_{2.5}$), as well as dysrhythmias, heart failure, and cardiac arrest was reported (RR=1.13 [95% CI: 1.05-1.21] per 10 μg/m3 $PM_{2.5}$).(62)

In the most recent re-analysis of the ACS cohort, the follow-up period was extended to 18 years.(63) In this second re-analysis, a random effects survival model was employed, and adjustment for 44 individual-level covariates as well as 7 ecological covariates was performed. This re-analysis, while producing slightly higher risk estimates, than previous studies, supported the association between $PM_{2.5}$ and all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortality.

3.2.3 Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality

In 2000, the original Havard Six Cities (2) and ACS (8) studies were validated on the basis of several criticisms regarding the methodologies of these two studies, and the associations between mortality and long-term exposure to $PM_{2.5}$ were supported.(64) In this re-analysis, potential effect modifiers were explored such as sex, age, and smoking; however, only education was found to modify the relationship between long-term exposure to $PM_{2.5}$ and mortality.(64)

3.2.4 Adventist Health Study of Smog (AHSMOG)

The AHSMOG cohort enrolled of 6,338 Seventh Day Adventists from California in 1976. Study participants completed a detailed lifestyle questionnaire in 1976, and monthly exposures to ambient concentrations of PM_{10} were obtained from 1966 to 1992. The first study of $PM_{2.5}$ and mortality in this cohort reported no significant association between $PM_{2.5}$ and all cause mortality.(65) In a second study of the AHSMOG cohort, a significant positive association between $PM_{2.5}$ and coronary heart disease mortality was reported for females, but not for males.(66)

3.2.5 Veterans Cohort

Approximately 70,000 U.S. male veterans previously diagnosed with hypertension were enrolled in the Veterans cohort. $PM_{2.5}$ data was obtained from 1999 to 2001, and mortality was followed-up from enrolment in1976 through to 2001. Individual-level and ecological variables were considered in the assessment.(67) All cause mortality was reported to be significantly associated with increasing $PM_{2.5}$, RR=1.12 per 10 $\mu g/m^3$ $PM_{2.5}$ (95% CI: 1.04-1.20).(67)

3.2.6 Women's Health Initiative (WHI) Study

In 1994 to 1998, the Women's Health Initiative (WHI) cohort enrolled 65,893 post-menopausal women living in the U.S. who had no history of cardiovascular disease. $PM_{2.5}$ exposure was estimated using data from ground monitors in closest proximity to each participant's residence, and the median follow-up period was 6 years.(68) A 76% increase in the risk of death from cardiovascular disease per 10 $\mu g/m^3$ of $PM_{2.5}$ was reported in the population of women. The risk estimates for $PM_{2.5}$ and mortality reported in this study, though comparable in direction and significance, were larger than those reported based on the ACS and Six Cities studies. The additional 10-12 years of follow-up associated with the ACS cohort study (9,63), as compared to the WHI cohort follow-up period of 6 six years, meant that the mortality rate due to cardiovascular events was approximately 8 fold greater (62); and, the $PM_{2.5}$ impacts may have been larger in the WHI population since $PM_{2.5}$ risk was being compared to a lower prevailing risk of cardiovascular death.(60)

3.2.7 Nurses' Health Study (NHS) Cohort

One air pollution study of the ongoing prospective NHS cohort aimed to assess the association between chronic PM_{10} and all-cause and coronary heart disease mortality in a population of 66,250 female nurses in the U.S. Follow-up of the cohort began in 1992, and questionnaires were completed by the participants bi-annually. Monthly $PM_{2.5}$ exposures were estimated at an individual level through use of a Geographic Information System-based model. All cause and coronary heart disease mortality was positively associated with PM_{10} exposure, and the magnitude of increased risk was greatest for exposure in the 24 months prior to mortality, where PM_{10} was associated with a 16% and 42% increased risk of mortality due to all causes and coronary heart disease.(69)

3.2.8 Medicare Cohort Studies

Medicare data has been the source of mortality data for several studies seeking to assess mortality in relation to long-term $PM_{2.5}$ exposure. Medicare databases include information on age and sex, for Americans ages 65 years and older.

Eftim et al. (2008) assessed the association between $PM_{2.5}$ and mortality using the same locations as the ACS and Six City studies. Mortality was obtained from Medicare data for the period 2000-2002, and was assessed in relation to averaged $PM_{2.5}$ concentrations obtained for the same period from EPA monitors in the same counties.(70) The authors reported significant increases in risk of all cause mortality, specifically, 10.9% and 20.8% for the ACS and Six Cities study counties respectively.(70) The higher estimates reported in this study compared to the ACS and Six Cities studies were predominantly thought to be due to the lack of personal confounder information and insufficient control for variables which are thought to influence mortality.(71)

The Medicare Cohort Air Pollution Study (MCAPS) was a retrospective cohort consisting of 13.2 million individuals 65 years of age or older who were enrolled in Medicare between 2000 and 2005. Individuals with zip codes indicating residence within 6 miles of an EPA $PM_{2.5}$ monitoring station were selected. Mortality risk was assessed in relation to 6-year average $PM_{2.5}$ exposures, and an 11.4% (95% CI: 8.8-14.1) and 20.4% (95% CI: 15.0-25.8) increased risk per 10 $\mu g/m^3$ was reported for eastern and central regions o f the U.S. respectively.(72)

3.2.9 Netherlands Cohort Study (NLCS)

The Netherlands Cohort Study enrolled approximately 120,000 subjects aged 55-69 years in 1986, and followed-up on mortality from 1987 through 1996. Confounder and effect modifier information was obtained from a questionnaire that subjects completed at enrolment, and from publicly available data. Average pollutant concentrations were estimated from the National Air Quality Monitoring Network (NAQMN). Non-significant increases in risk of all cause, cardiovascular, respiratory disease, and lung cancer mortality were reported in association with long-term $PM_{2.5}$ exposure.(73)

3.2.10 California Teachers Study (CTS)

The California Teachers prospective cohort study of active and former female public school professionals was initiated in 1995 and enrolled 133,479 individuals. Ostro et al. (2010) developed monthly averages of $PM_{2.5}$ exposures from June 2002 to July 2007 using the U.S. Environmental Protection Agency's Speciation Trends Network (STN) monitors, and mortality was followed-up in 45,000 women who lived within 30 km of an air pollution monitor. Significant increases in risk of all cause (HR=1.45 [95% CI: 1.36-1.55]), cardiopulmonary (HR=1.55 [95% CI: 1.43-1.69]), and ischemic heart disease (HR=1.91 [95% CI: 1.65-2.21]) mortality in relation to $PM_{2.5}$ were reported.(74)

3.3 Global Assessments of Mortality and Air Pollution

Using risk coefficients from Pope et al. (2002), the Comparative Risk Assessment (CRA) module of the World Health Organization's (WHO) global burden of disease (GBD) study estimated that fine particulate air pollution ($PM_{2.5}$) causes about 3% of mortality from cardiopulmonary disease, 5% of lung cancer mortality, and 1% of mortality from acute respiratory infections in children under 5 years.(10) When these air pollution causes of mortality were combined, it was estimated that they represent 1.4% of the total mortality attributable to the 26 risk factors assessed in the WHO global burden of disease project.(75)

3.4 Summary

In summary, the majority of cohort studies reported some degree of significant association between $PM_{2.5}$ and all cause, cardiovascular, respiratory disease, or lung cancer mortality. These findings were reflected in a 2006 expert elicitation report on the relationship between

$PM_{2.5}$ and mortality where three main contributors to mortality from long-term $PM_{2.5}$ exposure were stated: cardiovascular mortality, chronic respiratory disease, and lung cancer.(76)

Although not the focus of this review, a number of hypotheses based on physical or chemical properties of $PM_{2.5}$ have been put forth to explain a mechanism behind the health effects observed in association with these particles. Several of these theories are related to $PM_{2.5}$-associated metals, organics, acidity, oxidant activity or reactivity, and potentially toxic or allergenic biologic agents.(77) In terms of cardiovascular outcomes, commonly stated mechanisms of action based on the literature are: enhancement of atherothrombotic processes such as vascular oxidative stress, endothelial cell dysfunction, and atherosclerosis leading to platelet coagulation; and, activation of the autonomic nervous system such that changes in heart rate variability and dysrhythmias are triggered.(76,78) Altered pulmonary function, mild inflammation, oxidative responses, airway mucus cell hyperplasia, and allergic responses are most often reported in toxicological studies assessing long-term PM exposure and respiratory outcomes.(60) Finally, a review of epidemiological and toxicological studies summarized evidence indicating that PM is mutagenic in vivo and vitro.(79)

The ACS cohort is one of the longest cohort studies on $PM_{2.5}$ and mortality, and it has undergone numerous sets of independent analysis. The second re-analysis by Krewski et al. (2009) provides the most extensive control for confounders to date, and this thesis employed risk coefficients derived from this study. More details on the derivation of risk coefficients from this work will be provided in Section 5.6.

4.0 OBJECTIVES

The primary objective of this study was to undertake a global assessment of mortality associated with chronic exposure to fine particulate air pollution using remote sensory data.

The secondary objectives of this study were to:

- perform a literature review of the features of satellite derived measures of aerosol pollution;
- perform a literature review of cohort studies assessing long-term $PM_{2.5}$ exposure and mortality;
- estimate the fraction and number of all-cause, cardiopulmonary, lung cancer, and ischemic heart disease deaths attributable to the total and anthropogenic components of fine particulate air pollution;
- explore the sensitivity of estimates to:
  - selection of the concentration-response function;
  - selection of the theoretical minimum;
  - use of a maximum exposure threshold; and,
- compare the results from this study to those of the previous Global Burden of Disease (GBD) assessment for urban air pollution in order to comment on the feasibility of using satellite derived $PM_{2.5}$ concentrations in a global assessment of mortality.(10)

5.0 METHODS

5.1 Study Design Overview

The current study was designed to estimate the global population fractions of adult mortality and expected number of adult deaths that can be attributed to chronic exposure to fine particulate matter ($PM_{2.5}$). $PM_{2.5}$ exposure levels were derived from satellite imagery, and relative risks were calculated using pollution concentrations in conjunction with previously developed concentration-response functions for the association between $PM_{2.5}$ and four causes of mortality: all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease. Relative risk and mortality estimates were used to estimate the population fractions of mortality and expected number of deaths attributable to chronic $PM_{2.5}$ exposure. Mean $PM_{2.5}$ concentrations, relative risks, and attributable fractions were provided at country, World Health Organization (WHO) subregion, and global levels. Risk coefficients for the associations between $PM_{2.5}$ exposure and four causes of mortality were based on a prospective cohort study, while $PM_{2.5}$ concentrations and mortality were cross-sectional. The remaining methodology section will provide further details on each of the data collection and analytical components of this thesis.

5.2 The 2000 Global Burden of Disease Assessment for Urban Air Pollution

The methodology used in this work was based largely on the World Health Organization's (WHO) 2000 Global Burden of Disease (GBD) assessment for urban air pollution.(10,80) In order to confirm that the methods presented in the 2000 GBD were correctly interpreted, replication of their results was pursued for all major analytical components; and, where replication was not possible, further explorations of their methodology undertaken. The feasibility of using satellite-derived air pollution measures in a global burden of mortality assessment was examined by comparing the results of this thesis to those presented in the 2000 GBD.

5.3 World Health Organization Subregions

Country-level mean weighted $PM_{2.5}$ estimates, relative risks, and attributable fractions were aggregated to the WHO subregional level. In the WHO's GBD analyses, 192 member states are divided into five mortality strata based on WHO 1999 mortality rates in children less than 5 years of age as well as in males 15–59 years of age.(81) The five mortality strata are: A- very low child mortality, low adult mortality; B- low child mortality, low adult mortality; C- low child mortality, high adult mortality; D- high child mortality, high adult mortality; and, E- high child mortality, very high adult mortality.(81) These five strata are applied to the six WHO regions: Africa (AFR), Americas (AMR), South-East Asia (SEAR), Europe (EUR), Eastern Mediterranean (EMR), and Western Pacific (WPR), giving 14 subregions.

5.4 Fine Particulate Matter ($PM_{2.5}$) Concentrations

5.4.1 Mean Country-Level Ambient $PM_{2.5}$ Estimates

Country level ambient $PM_{2.5}$ concentrations were provided by Aaron van Donkelaar and Randall Martin of Dalhousie University. Estimates of average ambient fine particulate matter concentrations were provided for 231 countries/regions, and are presented in detail in Appendix A. The following information on the derivation of global $PM_{2.5}$ concentrations is a summary of the methods used by van Donkelaar et al., (82) and primarily summarizes information provided via personal communication.

Satellite-derived total-columnar AOD was combined with a chemical transport model to provide estimates of global $PM_{2.5}$ exposure. The chemical transport model GEOS-CHEM was used in these derivations to account for meteorological variability such as surface properties, humidity, temperature, winds, cloud properties, heat flux, and precipitation. Atmospheric emissions and chemistry, which also greatly affect aerosol optical properties and transport, were additionally used in the $PM_{2.5}$ derivations. Concentrations were also standardized to 35% relative humidity, and adjusted for sampling to better represent a true annual sample. Finally, data was adjusted for the dust, and to a smaller extent, sea salt fractions of $PM_{2.5}$. Removal of the dust component of $PM_{2.5}$ resulted in measurements that were thought to approximate the combustion, or anthropogenic components of $PM_{2.5}$. While dust can have an anthropogenic component, in the model used to make the separation between the 'total' and 'no dust' fractions of $PM_{2.5}$, dust was strictly natural. Natural dust emissions within the GEOS-Chem model are parameterized based upon wind speed and surface type. Conversely, anthropogenic dust emissions are a function of other factors such as traffic, mining, etc., which are not reflected in this parameterization, and are therefore not present in the model. In this thesis, ambient $PM_{2.5}$ concentrations were presented in formats that included the dust and sea salt components, $PM_{2.5\_Total}$, as well as excluded the non-combustion components of $PM_{2.5}$, $PM_{2.5\_No\ Dust}$.

Ambient country-level air pollution data was derived from a global 0.1° by 0.1° map of $PM_{2.5}$ concentrations, estimated from a composite average of MODIS and MISR total columnar aerosol measurements taken during 2001 through 2006. Each 0.1° by 0.1° pixel represents approximately 100 km^2 at mid latitudes. To have been included, a given pixel must have had a total of at least 5 valid measurements covering 3 separate years out of the 6 years of observation.

The data was averaged within country boundaries and weighted to 2005 population distributions. The satellite grids were combined with a 2.5' x 2.5' map of countries in order to extract all $PM_{2.5}$ pixels belonging to a given country. Then, 2.5' x 2.5' 2005 population density cells were multiplied with corresponding $PM_{2.5}$ pixels, summed at the country-level, and divided by country populations, giving mean weighted country-level $PM_{2.5}$ concentrations. Satellite derived $PM_{2.5}$ pixels were only associated with a single country or administrative region. For instance, the $PM_{2.5}$ values associated with the Chinese administrative regions Hong Kong and Macao are not included in $PM_{2.5}$ estimates for China.

The estimated 1-sigma (standard deviation) error of the $PM_{2.5}$ concentrations at 0.1° x 0.1° is ± 25%, which translates into a global population-weighted mean uncertainty of 6.7ug/m^3. Although the data was not available for this thesis, the uncertainty for country-level $PM_{2.5}$ estimates would be expected to decrease as data is being aggregated. The uncertainty value presented includes random measurement error, unpredictable error that does not affect the sample results in a consistent manner over repeated measures but rather increases the variability of the data, as well as systematic error which biases the sample results in the same direction over repeated measures, and affects the sample mean. Unfortunately, there is little information on the fraction of uncertainty that is random versus systematic, and without knowing the amount of error that random, it is difficult to propagate the uncertainty estimate into a variance estimate such as a standard deviation or confidence interval. Random errors, which affect precision, follow a Gaussian distribution and are described statistically by variance measures. Conversely, systematic errors are typically described in terms of bias, and are not usually incorporated into variance estimates but rather corrected for if the source of the error is known. Thus, without country-level uncertainty estimates or information on the random component of such estimates, this thesis does not propagate errors in $PM_{2.5}$ estimates into confidence intervals for relative risk and attributable fraction estimates.

5.4.2 Mean Weighted Subregional Ambient $PM_{2.5}$ Estimates

Mean weighted country-level $PM_{2.5}$ estimates were aggregated at the WHO subregion level. Of the 231 countries/regions in this dataset, 37 did not have a WHO subregion assigned in the 2004 World Health Report. In order to capture this valuable satellite data, subregions were assigned to these areas based on geographic location (i.e. their WHO region), as well as child and adult mortality. The potential impact of assigning countries/regions to subregions was assessed.

5.5 Mortality Data

5.5.1 Aerosol Pollution Causes of Mortality

Air pollution causes of mortality were selected based on the availability of risk estimates from a random effects model controlling for ecological covariates. Four air pollution causes of mortality, all cause, cardiopulmonary, lung cancer, and ischemic heart disease, were found to be significantly associated with $PM_{2.5}$ in the extended follow-up of the American Cancer Society (ACS) study linking particulate air pollution and mortality, and were included in this thesis.(63)

5.5.2 Data Extraction

Detailed country-level mortality data was obtained through primary collection from the detailed data files of the WHO Mortality Database. The WHO Mortality Data base comprises deaths registered in national vital registration systems, with underlying causes of death as coded by the relevant national authority. Countries included in this database are those that properly report vital statistics according to the International Classification of Diseases (ICD).

Due to the large volume of information contained in each data file, raw data files were downloaded in ASCII format and imported into Microsoft Access. At the time when these files were downloaded, they had last been updated in July of 2008. Raw data files contained number of deaths by country, year, sex, age group and cause of death, dating as far back as 1950. Microsoft Access was used to extract relevant country-level mortality data, and data was imported into Excel for ease of formatting and for eventual analysis.

WHOSIS data was extracted as it was originally thought that the mortality data available in WHOSIS could be used to supplement the WHO mortality database. However, the only outcome presented in the WHOSIS database relevant to this thesis was all cause mortality, and only mortality rates for the combined ages of 15-60 years were provided. Since this age range includes adolescents, and this study is only interested in assessing mortality in adults, the WHOSIS mortality data was not useful for this work.

Mortality data was collected for the year 2005 if possible, since 2005 population data was used to weight the $PM_{2.5}$ exposure data. When 2005 data did not exist, the next closest year of available data was obtained. In most instances, this resulted in the most recent year of mortality data available being gathered. The majority of countries reported mortality data using the 10th revision of ICD coding, while several countries reported using the 9th revision, and a few reported mortality data using the 7th and 8th revisions. Unique detailed data files existed for each of the four revisions of ICD coding, and they had to be downloaded and processed separately. In the instance where a country had mortalities recorded in the 'sex not specified' category, the deaths were split between the male and female categories.

Coverage was calculated by dividing the total number of deaths reported for a country-year from the vital registration system by the total number of estimated deaths for that year for the national population.(83) Coverage is distinct from completeness, which is the proportion of all deaths which are registered in the population covered by the vital registration system for a country.(83) A registration system may be complete for the population it covers, but may not cover the full population and all deaths occurring in the country. In this work, country-level mortality estimates were adjusted when coverage was less than 100%.

The risk coefficients that were modeled to represent the association between $PM_{2.5}$ and mortality were based on a population aged 30 years and older. The current analysis extracted mortality data for all ages, from which adult deaths, defined as ages 20 years and older, were determined. In comparison, the 2000 GBD for urban air pollution estimated the burden of disease for three health outcomes in different populations: mortality from cardiopulmonary causes in adults, mortality from lung cancer in all ages, and mortality from ARI in children aged 0-4 years.

5.5.3 International Classification of Diseases (ICD) Coding

The international classification of disease (ICD) coding used in this thesis to extract mortality data is consistent with that used in the derivation of the risk estimates employed in this thesis. Cardiopulmonary disease coding was defined by ICD-9 400-440 and 460-519, to be consistent with other relevant studies.(9,63,80) Lung cancer mortality was represented by ICD-9 code 162, which includes cancer of the trachea, bronchus and lung.(63) Ischemic heart disease mortality was represented by ICD-9 codes 410-414, as defined by the WHO Mortality Database Documentation,(63) as well as in the re-analysis of the ACS study.(64) All cause mortality is not represented by an ICD-9 code.

Table 5.1 summarizes ICD-9 coding in terms of detailed number lists, basic tabulation lists (BTL), as well as detailed causes of mortality. As indicated in Table 5.1, one small inadequacy of this version of coding existed for some countries that was related to defining cardiopulmonary disease mortality. Of the B30 series, cardiopulmonary disease only includes B300, atherosclerosis. However, Sri Lanka and San Marino reported ICD-9 coding to the 3rd character only, and therefore mortality due to the other B30 codes (B301-309) were included in the analysis. B30 was not excluded for these countries since atherosclerosis (B300) represents the majority of deaths in the B30 group. China, while it employed ICD-9 coding, had slightly different basic tabulation lists.

Table 5.1 Detailed list numbers and basic tabulation lists (BTL) for ICD-9 coding

Air Pollution Causes of Mortality	Detailed List Numbers	BTL[a]	Detailed Causes
All Cause		**B00**	**All causes**
Lung Cancer	**162**	**B101**	**Malignant neoplasm of trachea, bronchus and lung**
Cardiopulmonary Disease Including Ischemic Heart Disease (Cardiovascular)	**401-405**	**B26**	**Hypertensive disease**
	402, 404	B260	Hypertensive heart disease
		B269	Remainder of B26
	410-414	**B27**	**Ischaemic heart disease**
	410	B270	Acute myocardial infarction
		B279	Remainder of B27
	415-429	**B28**	**Diseases of pulmonary circulation and other forms of heart disease**
	415.1	B280	Pulmonary embolism
	427	B281	Cardiac dysrhythmias
		B289	Remainder of B28
	430-438	**B29**	**Cerebrovascular disease**
	430	B290	Subarachnoid haemorrhage
	431, 432	B291	Intracerebral and other intracranial haemorrhage
	433, 434	B292	Cerebral infarction
	436	B293	Acute but ill-defined cerebrovascular disease
	437	B294	Cerebral atherosclerosis
		B299	Remainder of B29
	440-459[b]	**B30**[b]	**Other diseases of the circulatory system**
	440	B300	Atherosclerosis
Cardiopulmonary Disease (Respiratory)	**460-465, 470-478**	**B31**	**Diseases of the upper respiratory tract**
	463	B310	Acute tonsillitis
	464	B311	Acute laryngitis and tracheitis
	460-462, 465	B312	Other acute upper respiratory infections
	470, 471	B313	Deflected nasal septum and nasal polyps
	472, 473	B314	Chronic pharyngitis, nasopharyngitis and sinusitis
	474	B315	Chronic diseases of tonsils and adenoids
		B319	Remainder of B31

466, 480-519	**B32**	**Other diseases of the respiratory system**
466	B320	Acute bronchitis and bronchiolitis
480-486	B321	Pneumonia
487	B322	Influenza
490-493	B323	Bronchitis, chronic and unspecified, emphysema and asthma
494	B324	Bronchiectasis
495, 496	B325	Other chronic obstructive pulmonary disease
500-508	B326	Pneumoconiosis and other lung disease due to external agents
511	B327	Pleurisy
	B329	Remainder of B32

[a] BTL coding was used in the mortality database to identify cause of death; depending on the country, BTL codes B26-B32 where reported at either 3rd or 4th character levels
[b] For the BTL code B30, only B300 (4th character) was required; Sri Lanka and San Marino had ICD-9 coding to the 3rd character only, and mortalities due to B301-309 were included for these countries

Conversion of ICD-9 to ICD-10 coding was done using an online conversion tool produced by Timely Data Resources(84) in conjunction with the WHO's database documention.(83) Table 5.2 shows the 3rd character level detailed list numbers for ICD-10 compared to ICD-9. In general, all cause mortality was represented by ICD-10 code C01, cardiopulmonary disease mortality by I10-70 and J00-99, lung cancer mortality by C33-34, and ischemic heart disease by I20-25.

Table 5.2 Comparison of detailed list numbers for ICD-9 and ICD-10 coding

Air Pollution Causes of Mortality	Detailed List Numbers for ICD-9	Detailed List Numbers for ICD-10[a]	ICD-10 Data Codes[b]	Detailed Causes
All Cause	-	C01	1000	All causes
Lung Cancer	162	C33-C34	1034	Malignant neoplasm of trachea, bronchus and lung
Cardiopulmonary Disease Including Ischemic Heart Disease (Cardiovascular)	401-440	I10-I13	1066	Hypertensive diseases
		I20-I25	1067	Ischaemic heart diseases
		I26-I51	1068	Other heart diseases
		I60-I69	1069	Cerebrovascular diseases
		I70	1070	Atherosclerosis
Cardiopulmonary Disease (Respiratory)	460-519	J00-J98	1072	Diseases of the respiratory system
		J10-J11	1073	Influenza
		J12-J18	1074	Pneumonia
		J20-J22	1075	Other acute lower respiratory infections
		J40-J47	1076	Chronic lower respiratory diseases
		J00-J06, J30-J39, J60-J98	1077	Remainder of diseases of the respiratory system

[a] ICD-10 detailed list numbers were used in the mortality database to identify cause of death

[b] Data codes were used to identify causes of death for some countries instead of detailed list numbers

A few countries also reported mortality using ICD-7 and ICD-8 coding. Mortality for Taiwan was reported using ICD-7 and mortality for Cape Verde, Iran, and Turkey was reported using ICD-8. The relevant ICD-7 and 8 detailed list numbers and BTL codes were selected using the WHO's database documentation.(83)

5.5.4 Approximation of Age Distributions

Several countries did not report mortality data by age, and thus mortality distributions were not available to calculate deaths for adults ages 20 years or older. These countries were Cape Verde, Sri Lanka, Papa New Guinea, and Seychelles. Mortality distributions for these countries were imputed by approximating to known distributions for countries with similar population age structures, birth rates, and death rates. This population information was obtained the Central Intelligence Agency's (CIA) World Fact Book.(85) Cape Verde's population distribution was approximated to that of Sao Tome and Principe, Sri Lanka to Thailand, Papa New Guinea to the Philippines, and Seychelles to Maldives.

5.5.5 Validation of Mortality Data

Since data extraction was only performed by one individual, several validation measures were implemented to enhance accuracy of the mortality data. First, the WHO online mortality tables were consulted to verify the total number of deaths for all four air pollution causes of mortality.(86) These mortality data tables, which had to be consulted individually for each country, provided aggregated number of deaths for each of the outcomes of interest for males and females separately. Data could be verified for all countries except for Cape Verde, China, Honduras, Iran, Macao, Macedonia, Pakistan, Taiwan, and Turkey, which, despite having detailed mortality data files, did not have online WHO aggregated data. These online WHO aggregated tables could not be used to extract data for the thesis since the age categories given do not match the age ranges of interest. The WHO online aggregated data provided number of deaths for the age categories 15-24 and 25-34 years; and therefore, the analysis for adults (≥20 years) would not have been possible using this source. Due to these restricted age categories, this method of validation could only be performed for all ages.

In an attempt to verify the number of deaths derived from the detailed data files for age's ≥20 years, it was ensured that the number of deaths for adults was less than that for all ages, and that the ratio for male to female deaths remained roughly the same across both age categories. If it was observed, for example, that there were a higher number of deaths in adults than in all ages for a particular country, the detailed data files were verified to see where the mistake had been made. Similarly, if 2/3 of the deaths occurred in males for the all ages category but then that ratio changed to 1/2 or 1/3 in those ≥20 years, that country's detailed mortality data were scrutinized further. These methods managed to capture several data entry errors.

Another method of data verification was to assess the number of deaths occurring in adults versus children. It was thought that if the burden of mortality was abnormally high among those aged <20 years of age, this could indicate a data extraction or formatting error. For all cause mortality, a country's detailed data extraction spreadsheets were verified if the ratio of adult (≥ 20 years) deaths to deaths for all ages was less than 70%. For cardiopulmonary disease mortality, which includes respiratory disease, data were examined further when that ratio was less than 90%. For ischemic heart disease and lung cancer, where deaths from these causes occur primarily in adults, mortality data was scrutinized for ratios less than 97%.

One final note regarding data verification; when the total number of deaths for a particular air pollution cause of mortality was zero for a country as a whole or for one gender, additional scrutiny of data was conducted. All entries of zero mortality were carefully verified by using the WHO online mortality tables and by reviewing the original data extraction files.

5.5.6 Comparison with the 2004 GBD Subregional Mortality Estimates

In late 2008, the World Health Organization released its most recent update to the Global Burden of Disease project, with 2004 estimates of mortality, disability, and loss of health for 135 causes at the *subregional* level (note: data not available at the country-level). Subregional estimates for the air pollution causes of mortality of interest in 2004 were obtained and compared to the mortality estimates derived in this thesis from the WHO mortality database.

Due to the methods employed in this thesis (section 5.6), country-level mortality estimates provided by the WHO mortality database were required to calculate attributable fractions of mortality. However, due to the improved accuracy of the mortality estimates provided by the 2004 WHO GBD update as a result of modelling activities, when calculating the subregional and global expected numbers of deaths, mortality estimates from the 2004 GBD update was employed.

5.5.7 Issues Surrounding All Cause Mortality

The validity of assessing global all cause mortality based on risk coefficients derived from a U.S. population was addressed by assessing the consistency of the ratio of cardiopulmonary deaths to total mortality in each region with those observed in the US.

5.5.8 Impact Assessment: Removal of Countries with Outdated Mortality Data

The impact of using mortality data that was ≥10 years older than 2005, the year of the population data used to weight the $PM_{2.5}$ exposures, was explored. Base case subregional and global attributable fractions were calculated both including and excluding countries with outdated mortality, and estimates were compared.

5.6 Global Assessment of Mortality Attributable to $PM_{2.5}$

5.6.1 Base Case Scenario

A base case assessment of the attributable fractions of mortality and the numbers of deaths associated with $PM_{2.5}$ was performed for the total as well as the anthropogenic components of fine particulate air pollution, $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$.

5.6.1.1 Concentration-response function

The term 'concentration-response' (C-R) function is used throughout this thesis in lieu of 'exposure-response' to describe the risk functions. This is consistent with other epidemiological studies that assess exposure to air pollution, where exposure is presented in terms of ambient concentrations. The base case scenario was derived using the following function relating chronic $PM_{2.5}$ exposure to risk of mortality:

$$RR_{X-X_0} = \exp\left[\frac{\alpha + \beta X}{\exp(\alpha + \beta X_0)}\right]$$

$$= \exp[\beta(X - X_0)] \qquad \textit{(Equation 1)}$$

where:

- RR_{X-X_0} is the relative risk at exposure 'X', compared to the reference exposure 'X_0';
- β is the parameter estimate for the association between chronic $PM_{2.5}$ exposure and cause of mortality;
- X is the mean $PM_{2.5}$ ambient concentration based on satellite data; and,
- X_0 is the theoretical minimum or reference level for $PM_{2.5}$.

The terminology used in the literature for this equation is confusing. For example, in the 2000 GBD for urban air pollution, *Equation 1* is referred to as 'log-linear', while in an environmental burden of disease (EBD) assessment of outdoor air pollution it was referred to it as 'linear'.(1) Furthermore, the 2000 GBD for urban air pollution assumes *Equation 1* for their base case analysis, which they call 'log-linear' despite it being an exponential model, and they use what are termed 'linear' risk coefficients in this model. Moreover, they discuss exploring a sensitivity scenario where excess mortality increases with the log of concentration of $PM_{2.5}$ across the entire range; under this scenario, they employ risk coefficients termed 'log-linear'.

To clarify, *Equation 1*, the original C-R function derived from the ACS air pollution study, is an exponential risk function typical of most epidemiological models when exposure concentrations are relatively low. Mathematically, one of the characteristics of the exponential function, $\exp(b * x)$, is that at low concentrations it can be approximated to the linear function, $1 + b * x$, because $b * x$ is small due to small x. This was shown to be true in a re-analysis of the original American Cancer Cohort (ACS) study by Pope et al. (1995), where it was found that the association between $PM_{2.5}$ and all-cause as well as cardiopulmonary mortality were nearly linear within the ranges of fine particulate matter observed for the cohort, 7-30ug/m^3.(64) Similarly, in an extended analysis, the shape of the exponential concentration-response function was explored again and found to be linear in the ranges of data observed, 5-30ug/m^3.(9) For this reason, the exponential function and associated risk coefficients are sometimes termed linear in the literature. For the purposes of this thesis, *Equation 1* will be referred to as the linear exposure model, since risk, while actually increasing exponentially with concentration, *appears* to be increasing linearly with ambient $PM_{2.5}$ concentration within lower concentration ranges observed for most countries in this work. A log-linear model will also be explored, and will be discussed in the section outlining the sensitivity analyses.

5.6.1.2 Risk Coefficients

The parameter estimates for the association between $PM_{2.5}$ and mortality were based on the ongoing prospective American Cancer Society (ACS) cohort study. Risk coefficients were derived from risk estimates presented in the most recent analysis of the American Cancer Society study of $PM_{2.5}$ and mortality.(63) Risk coefficients used in the 2000 GBD for urban air pollution were also modelled from the ACS study.

The ambient air pollution data used in the ACS study to estimate exposure to particulate air pollution was collected from 1979 to 1983, and more recently from 1999 to 2000. The original analysis of air pollution and mortality was based on pollution data from 1979 to 1983,(8) whereas an extended analysis in 2002 included $PM_{2.5}$ data from 1999 and 2000.(9) Risk coefficients in this thesis were derived from risk estimates based on the most recent air pollution data (1999-2000) which corresponds to the satellite data collection period (2001-2006).

In the enhanced spatial assessment of the 2009 ACS analysis, the confounding and modifying effect of ecological covariates on the air pollution-mortality association was examined at various scales, and multiple level spatial autocorrelation was assessed within the random effects Cox model. The 2009 extended follow-up employed a multi-level random effects Cox survival model capable of handling several levels of geographic clustering. Only pollutant-causes of death initially identified to be statistically significant in the standard Cox survival model were assessed in a random effects model, such that risk coefficients for all-cause, lung cancer, ischemic heart disease, and cardiopulmonary mortalities were run in the random effects model.(63)

Hazard ratios for all-cause, lung cancer, cardiopulmonary disease and ischemic heart disease mortality associated with $PM_{2.5}$ (1999-2000) were derived from the following random effects survival model:(63)

- one level of clustering at the metropolitan statistical level (MSA);
- adjustment for 44 individual covariates broken down as follows: 8 variables representing active smoking habits; 7 variables characterizing former smoking habits; 1 variable for exposure to passive smoke; 2 variables representing marital status; 2 variables representing a linear and squared term for body mass index; 6 variables characterizing alcohol consumption; 7 variables characterizing the subject's occupation and potential exposure to PM in the work place; 1 variable representing self reported exposure to dust and fumes in the workplace; 8 variables representing diet; and, 2 variables characterizing education;
- adjustment for seven ecological covariates: percentage of homes with air conditioning, percentage of adults with less than grade 12 education, percentage non white population, percentage of unemployed persons over the age of 16 years, median household income, income disparity (measured by the GINI Coefficient), and 125% of poverty line; and,
- stratification of the baseline hazard function by 1-year age groupings, gender, and race.

Table 5.3 presents the linear risk coefficients used in this thesis which were derived from the hazard ratios presented in the extended follow-up of the American Cancer Society (ACS) study linking particulate air pollution and mortality.

Table 5.3 Derivation of linear risk coefficients (β) from hazard ratios (HR) in the extended follow-up of the American Cancer Society study linking particulate air pollution and mortality

Pollutant Causes of Death	Ecological Covariate Adjustment	$PM_{2.5}$ (1999-2000) HR[a] per 10 μg/m^3			Corresponding β[b] per 1 ug/m^3		
		Point Estimate	95% CI, Lower Bound	95% CI, Upper Bound	Point Estimate	95% CI, Lower Bound	95% CI, Upper Bound
All Cause Mortality	none	1 060	1 024	1 097	0 005827	0 002372	0 009258
	MSA & DIFF[c]	**1.078**	**1.043**	**1.115**	**0.007511**	**0.004210**	**0.010885**
Cardiopulmonary Disease Mortality	none	1 094	1 040	1 150	0 008984	0 003922	0 013976
	MSA & DIFF[c]	**1.128**	**1.077**	**1.182**	**0.012045**	**0.007418**	**0.016721**
Lung Cancer Mortality	none	1 122	1 040	1 210	0 011511	0 003922	0 019062
	MSA & DIFF[c]	**1.142**	**1.057**	**1.234**	**0.013278**	**0.005543**	**0.021026**
Ischemic Heart Disease Mortality	none	1 196	1 103	1 298	0 017898	0 009803	0 026082
	MSA & DIFF[c]	**1.287**	**1.177**	**1.407**	**0.025231**	**0.016297**	**0.034146**

[a] From Table 11,(63) HRs were based on linear functions using the Cox Random Effects Survival Model with one level of clustering (MSA), adjusting for 44 individual covariates, and stratifying the baseline hazard function by age (1-year groupings), gender, and race
[b] Risk coefficients were calculated based on the linear risk function presented in *Equation 1*
[c] 'MSA' is the metropolitan statistical area level and 'DIFF' is the difference between the mean zip code level (ZCA) and MSA level values

The current work employed risk coefficients that had ecological covariate adjustment Specifically, the largest decrease in residual variation occurred when ecological covariates were decomposed into between ('MSA' in Tables 5 3 and 5 4) and within ('DIFF' in Tables 5 3 and 5 4) metropolitan statistical level values

5.6.1.3 Theoretical-Minimum Concentration

For the base case scenario, the theoretical-minimum value was set to 5.8μg/m^3, the lowest concentration observed in the 1999-2000 $PM_{2.5}$ exposure collection period.(63)

5.6.2 Derivation of Subregional Relative Risks

Linear subregional-specific relative risks associated with $PM_{2.5}$ for outcome '*i*' in subregion '*k*' were determined as follows:

- the theoretical minimum exposure (X_0) was first subtracted from country-level mean weighted $PM_{2.5}$ concentrations (X_c);
- then, each country-level X_c-X_0 value was multiplied by the proportion of the subregion exposed at that level (P_c), where P_c = (country '*c*' population within subregion '*k*')/ (subregion '*k*' population);
- next, country-level $P_c*(X_c-X_0)$ values were summed at the subregional level, essentially giving a weighted subregional exposure average, termed *Ck*; and,
- finally, *Ck* values were inputted into the linear risk function such that $RR_k = \exp(\beta_i * C_k)$.

The log-linear subregional-specific relative risk estimates associated with $PM_{2.5}$ for outcome '*i*' in subregion '*k*' were calculated by inserting the mean weighted subregional $PM_{2.5}$ ambient concentrations into the log-linear risk function along with the reference exposure level.

5.6.3 Derivation of Subregional and Global Fractions of Mortality Attributable to $PM_{2.5}$

The detailed chapter of the World Health Organization's global burden of disease (GBD) assessment for urban air pollution does not provide much information on the methods used to calculate the fractions of mortality that can be attributed to chronic fine particulate matter exposure.(80) Instead, the reader is directed to two generic chapters which outline the general framework used for estimating the global burden of disease attributable to specific risk factors.(87,88)

The potential impact fraction (PIF) is the fraction of disease or death attributable to the risk factor in a population, and is given by:

$$PIF = \frac{\sum_{i=1}^{n} P_i * RR_i - \sum_{i=1}^{n} P_i' * RR_i}{\sum_{i=1}^{n} P_i * RR_i} \quad \textit{(Equation 2a)}$$

where:

- RR_i = relative risk at exposure category '*i*';
- P_i = proportion of population at exposure category '*i*';
- P_i' = proportion of population at counterfactual exposure; and,
- n = levels of exposure.(87)

The PIF can be used to estimate the population attributable fraction (PAF), or simply the attributable fraction (AF), defined as the proportional reduction in disease or death that would occur if exposure to the risk factor were reduced to the reference or theoretical minimum exposure distribution. By using a theoretical-minimum-risk exposure distribution as the counterfactual exposure distribution, which by definition has a relative risk of 1.0, *Equation 2a* is reduced to:(87)

$$AF = \frac{\sum_{i=1}^{n} P_i (RR_i - 1)}{\sum_{i=1}^{n} P_i (RR_i - 1) + 1} \quad \textit{(Equation 2b)}$$

Equations 2a and *2b* take into account various population groups exposed at different ambient pollution concentrations, such that the sum of the proportions at all exposure categories, including the unexposed, should equal 1. However, in the case where the population is one country with only one exposure level, *Equations 2b* can be simplified to:(1)

$$AF = \frac{RR_{X-X_0} - 1}{RR_{X-X_0}} \quad \textit{(Equation 3)}$$

In this thesis, *Equation 3* was used to derive the fraction of mortality attributable to $PM_{2.5}$ for each aerosol pollution cause of mortality.

In the WHO GBD assessments, determining the AF for a particular risk factor and disease outcome pair at the subregional level involves using *Equation 2b* to calculate population attributable fractions (PAFs) for 8 age, 2 sex, and 14 subregion groups, for a total of 224 cells.(87,88) Mortality attributable to a particular risk factor is then calculated for each of the 224 cells by multiplying each cell's PAF by the number of deaths due to the disease per cell.(87,88) Finally, the attributable mortality estimates are aggregated across the 16 age-sex cells within a subregion and dividing by the total subregional disease mortality.(87,88) However, since the risk coefficients for the association between $PM_{2.5}$ and the four causes of mortality used in this thesis are not available stratified by age and sex, calculation of PAFs broken down by age and sex would not have been a worthwhile exercise since the relative risks used to calculate the PAFs would have been the same across all age-sex cells. Instead, the following methodology was employed to calculate the subregional and global attributable fractions of mortality in this thesis:

- the mortality attributable to $PM_{2.5}$ for each country was calculated by multiplying the number of adult (≥20 years) all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease deaths for a particular country by the attributable fraction calculated for that country;
- the attributable mortality estimates were aggregated to the subregional level and divided by the total subregional disease mortality; and,
- the mean of all subregional AFs were used to develop a global attributable fraction estimate.

This method takes into account the relative size and mortality rates of the included countries. The differences in methodologies used to calculate the attributable fractions in this work compared to the 2000 GBD for urban air pollution will be discussed when the results of the two works are compared.

5.6.4 Sensitivity Analyses

The selection of the concentration-response function and the theoretical minimum, as well as use of a maximum exposure threshold was explored in several sensitivity analyses.

5.6.4.1 Concentration-response function

When extrapolating beyond the highest ambient $PM_{2.5}$ exposure levels observed in the ACS cohort, $30 \mu g/m^3$ (observed during the 1979-1983 collection period),(9,63,80) it has been suggested that use of a linear function may be inappropriate since it could overestimate mortality; and, the use of a log-linear exposure function has been recommended such that its slope would flatten at higher $PM_{2.5}$ concentrations.(1) It is common for linear and log-linear extrapolations to be explored in sensitivity analyses when estimating mortality due to long-term exposure to $PM_{2.5}$,(1,80,89) and this was explored in this thesis as well for both the total and anthropogenic components of $PM_{2.5}$.

The following log-linear concentration-response function was used in this thesis:

$$RR_{X-X_0} = \exp\left[\frac{\alpha + \gamma \ln(X+1)}{\alpha + \gamma \ln(X_0+1)}\right]$$

$$= \exp\left[\frac{X+1}{X_0+1}\right]^{\gamma} \qquad \textit{(Equation 4)}$$

where:

- RR_{X-X_0} is the relative risk at exposure 'X', compared to the reference exposure 'X_0';
- γ is the parameter estimate for the association between chronic $PM_{2.5}$ exposure and cause of mortality;
- X is the mean $PM_{2.5}$ ambient concentration based on satellite data; and,
- X_0 is the theoretical minimum or reference level for $PM_{2.5}$.

It can be noted that *Equation 4* is not in typical log-linear form, and few details on its derivation are provided in the 2000 GBD for urban air pollution. *Equation 4* is derived from the equation $RR_{X-X_0} = \exp\left[\frac{\alpha + \gamma \ln X}{\alpha + \gamma \ln X_0}\right]$, which is transformed by adding 1 to both concentrations. This was done in order to avoid taking the log of zero, and to dampen the effect whereby the log-linear risk function gets very steep near zero, which physiologically is not likely the case (R. Burnett, personal communication).

Table 5.4 Derivation of log-linear risk coefficients (β) from hazard ratios (HRs) in the extended follow-up of the American Cancer Society study linking particulate air pollution and mortality (95% confidence intervals)

Pollutant Causes of Death	Ecological Covariate Adjustment	Log $PM_{2.5}$ (1999-2000) HR_1[a] (from 5 to 15μg/m^3)	Log $PM_{2.5}$ (1999-2000) HR_2[a] (from 10 to 20μg/m^3)	Corresponding γ[b] per 1ug/m^3		
				Point Estimate	95% CI, Lower Bound	95% CI, Upper Bound
All Cause Mortality	none	1.095 (1.044-1.148)	1.059 (1.028-1.091)	0.09059	0.04330	0.13770
	MSA & DIFF[c]	**1.128 (1.077-1.183)**	**1.079 (1.048-1.112)**	**0.12019**	**0.07407**	**0.16776**
Cardiopulmonary Disease Mortality	none	1.145 (1.068-1.228)	1.089 (1.042-1.138)	0.13495	0.06535	0.20466
	MSA & DIFF[c]	**1.208 (1.132-1.290)**	**1.127 (1.081-1.174)**	**0.18878**	**0.12343**	**0.25385**
Lung Cancer Mortality	none	1.193 (1.071-1.330)	1.118 (1.044-1.197)	0.17621	0.06826	0.28442
	MSA & DIFF[c]	**1.236 (1.114-1.372)**	**1.143 (1.071-1.221)**	**0.21136**	**0.10807**	**0.31562**
Ischemic Heart Disease Mortality	none	1.315 (1.175-1.470)	1.188 (1.107-1.275)	0.27280	0.16081	0.38425
	MSA & DIFF[c]	**1.484 (1.311-1.680)**	**1.283 (1.186-1.378)**	**0.39392**	**0.26995**	**0.51239**

[a] From Table 11,(63) HRs were based on log-linear functions using the Cox Random Effects Survival Model with one level of clustering (MSA), adjusting for 44 individual covariates, and stratifying the baseline hazard function by age (1-year groupings), gender, and race; log-linear risk estimates were presented for two overlapping ranges, 5 to 15μg/m^3 and 10 to 20μg/m^3

[b] Risk coefficients were calculated based on the log-linear risk function presented in *Equation 4*; coefficients were calculated separately for each range and the averages of the two values were used as the overall coefficient for the log-linear C-R function

[c] 'MSA' is the metropolitan statistical area level and 'DIFF' is the difference between the mean zip code level (ZCA) and MSA level values

Table 5.4 presents the log-linear risk coefficients used in this thesis which were derived from the hazard ratios presented in the extended follow-up of the American Cancer Society (ACS) study linking particulate air pollution and mortality. The log-linear hazard ratios and their associated risk estimates were higher for the lower $PM_{2.5}$ range, 5 to 15μg/m^3, as compared to the higher range, 10 to 20μg/m^3, for the four causes of death. By averaging the log-linear coefficients for both ranges, log-linear risk estimates were effectively underestimated for countries with $PM_{2.5}$ levels less than 10μg/m^3, and overestimated for countries with ambient concentrations greater than 15μg/m^3.

5.6.4.2 Theoretical-minimum concentration

Since the base case reference value ignores any potential health benefits that may arise when reducing $PM_{2.5}$ concentrations below 5.8μg/m^3, several sensitivity scenarios were assessed where the reference value was set to the lowest levels observed for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ concentrations, 2.1μg/m^3 and 0.8μg/m^3 respectively. In addition to assessing this sensitivity scenario for the total and anthropogenic components of $PM_{2.5}$, it was also explored for the linear and log-linear models, giving rise to four cases.

5.6.4.3 Maximum exposure threshold

To assess the impact of extrapolating risk beyond the highest ambient $PM_{2.5}$ exposure levels observed in the ACS cohort, 30μg/m^3 (observed during the 1979-1983 collection period),(9,63,80) risk was maximized under two scenarios.

First, a scenario was run where excess risk was constrained to be no greater than that associated with a concentration of 30μg/m^3. This sensitivity scenario, which was also run in the previous GBD, will only be explored for $PM_{2.5\_Total}$ because once the dust component is removed there remain only two countries that have ambient concentrations above 30μg/m^3, China and Macao.

Second, a scenario was explored whereby risk was maximized at the point where the linear and log-linear models intersect. Figure 5.1 shows a comparison between linear and log-linear models for all four pollution causes of mortality of interest. The linear models provide lower risk estimates than the log-linear model up until they intersect, after which point the log-linear model provides lower risk estimates. The point of intersection is similar for all four causes. The models intersected at 43.75μg/m^3 for cardiopulmonary disease mortality, 44μg/m^3 for ischemic heart disease mortality, 44.75μg/m^3 for lung cancer mortality, and 46μg/m^3 for all cause mortality. The only two countries that have ambient $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ concentrations above the linear and log-linear model intersection points are

China and Macao. This scenario was only explored for the total component of $PM_{2.5}$ as the ambient concentration for China falls at or below the intersection points once the dust component is removed. Similarly once the dust component is removed, ambient concentrations for Macao approach the intersection point values.

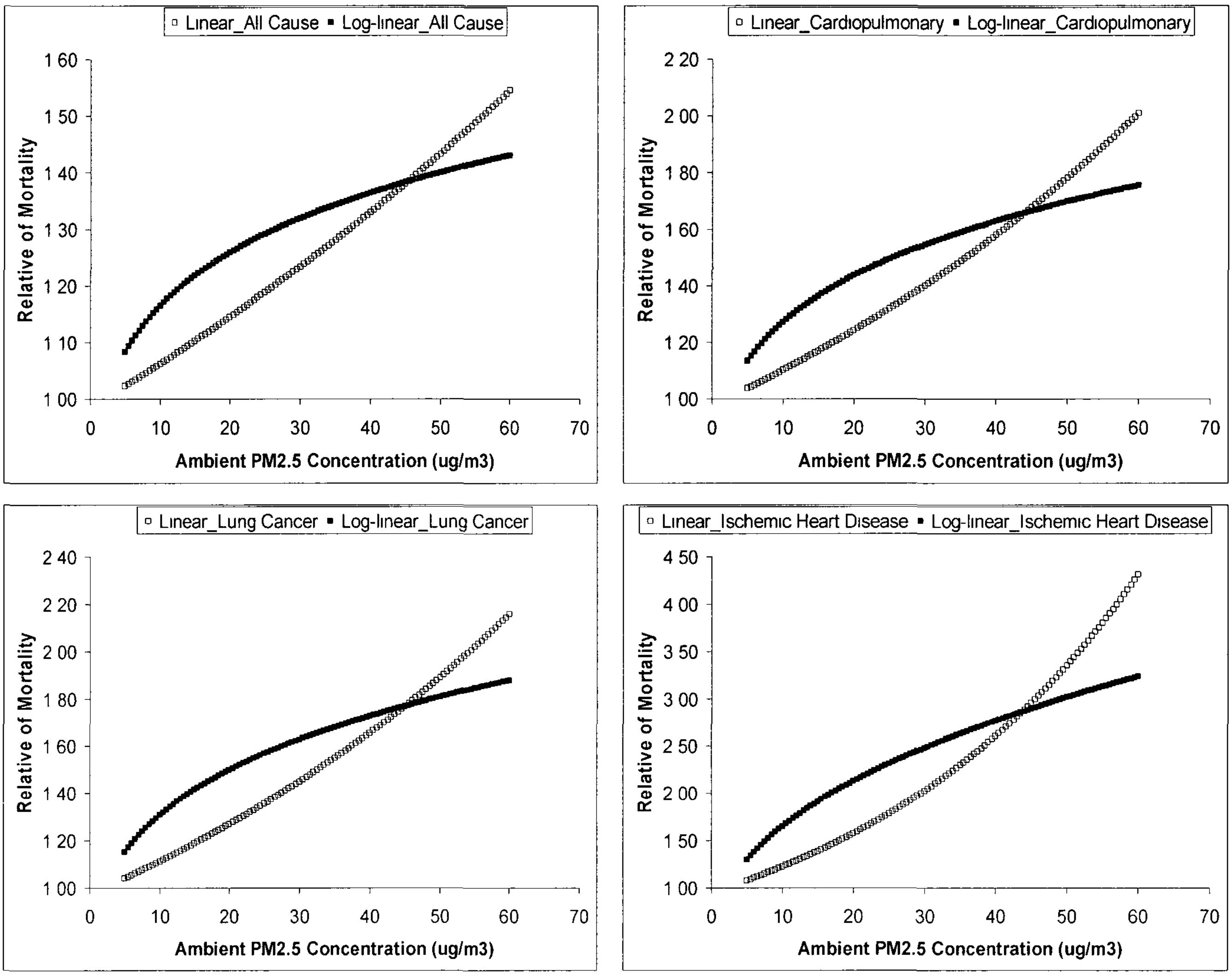

Figure 5.1 Linear and log-linear models for all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortality under a hypothetical exposure scenario

5.6.5 Impact Assessment: Removal of Countries Lacking Mortality Data

Since calculation of attributable fractions and expected number of deaths requires data on the rate of mortality, subregional and global estimates were based the countries for which there was $PM_{2.5}$ *and* mortality data. The impact of excluding countries that were lacking mortality data from the analysis was assessed.

5.6.6 Summary of Analyses

Table 5.5 provides an outline of the previously discussed scenarios used to calculate relative risks in this thesis. In total, 10 cases were explored in this work, including 2 base cases for the total and anthropogenic components of $PM_{2.5}$ as well as 8 sensitivity analyses.

Table 5.5 Summary of analyses

Case	Description of Sensitivity Scenario	Fraction of $PM_{2.5}$	Shape of the Concentration-Response Curve	Reference Concentration ($\mu g/m^3$)	Maximum Exposure ($\mu g/m^3$)
1_{Total}	Base case	Total	Linear	5.8	Excess mortality increases exponentially across entire range
$1_{No\ Dust}$		No Dust	Linear	5.8	
2_{Total}	Selection of C-R function	Total	Log-linear	5.8	Excess mortality increases with log of $PM_{2.5}$ concentration across entire range
$2_{No\ Dust}$		No Dust	Log-linear	5.8	
3_{Total}	Theoretical-minimum	Total	Linear	2.1	Excess mortality increases exponentially across entire range
$3_{No\ Dust}$		No Dust	Linear	0.8	
4_{Total}		Total	Log-linear	2.1	Excess mortality increases with log of $PM_{2.5}$ concentration across entire range
$4_{No\ Dust}$		No Dust	Log-linear	0.8	
5	Maximum exposure threshold	Total	Linear	5.8	No increase in excess mortality beyond $30\mu g/m^3$
6		Total	Linear	5.8	No increase in excess mortality beyond the intersection point of the linear and log-linear models

6.0 RESULTS

6.1 Fine Particulate Matter ($PM_{2.5}$) Concentrations

Overall, there was good agreement between coincident 24-hour satellite-derived and ground-based $PM_{2.5}$ estimates in North America (r = 0.78, slope = 1.02, n = 1083), and with non-coincident measurements elsewhere (r = 0.83, slope = 0.86, n = 244).

6.1.1 Mean Country-Level Ambient $PM_{2.5}$ Estimates

The range of mean weighted $PM_{2.5\_Total}$ concentrations was 2.1µg/m^3 to 51.5µg/m^3, while the range of mean $PM_{2.5\_Total}$ concentrations not weighted to the population was 1.8µg/m^3 to 51.4µg/m^3. The ranges of weighted and unweighted $PM_{2.5\_No\ Dust}$ were the same, with boundary concentrations slightly lower than $PM_{2.5\_Total}$ The range of mean weighted and unweighted $PM_{2.5\_No\ Dust}$ concentrations was 0.8µg/m^3 to 47.4µg/m^3.

The mean of country $PM_{2.5\_Total}$ concentrations was 13.1µg/m^3 and the median was 11.4µg/m^3 when weighted to the population. When not population weighted, the mean and median of all country $PM_{2.5\_Total}$ concentrations were similar at 12.8µg/m^3 and 10.3µg/m^3 respectively. The mean of country $PM_{2.5\_No\ Dust}$ concentrations was 6.1µg/m^3 and the median was 4.6µg/m^3 when weighted to the population. When not population weighted, the mean of all country $PM_{2.5\_No\ Dust}$ concentrations was 5.4µg/m^3 and median was 4.2µg/m^3. The similarities between mean and median values indicate that country-level $PM_{2.5}$ concentrations are likely normally distributed when weighted and unweighted to the population, for the total as well as anthropogenic components of $PM_{2.5}$.

The mean of country $PM_{2.5\_Total}$ concentrations was significantly different from $PM_{2.5\_No\ Dust}$ concentrations ($p < 0.0001$, $\alpha = 0.05$, n=231). A *matched* t-test was performed since ambient $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ concentrations for each country were dependent.

The $PM_{2.5}$ data also included the proportion of the country area as well as the proportion of the population which is represented by the mean country $PM_{2.5}$ ambient exposure estimate.

Geographic coverage of the $PM_{2.5}$ data was generally good, with proportions ranging from 4 to 100%. Mean geographic coverage was 88% and median coverage was 97%. Similarly, population coverage of the $PM_{2.5}$ data was generally good, with proportions ranging from 2 to 100%. Mean population coverage was 93% and median coverage was 99%.

6.1.2 Mean Weighted Subregional Ambient $PM_{2.5}$ Estimates

Of the 231 countries/regions in this dataset, 37 did not have a WHO subregion assigned in the 2004 World Health Report, and subregions were assigned to these areas based on geographic location (i.e. their WHO region) as well as child and adult mortality. These 37 areas and their assigned WHO subregion are shown in Appendix A; they represent only 0.6% of the population covered by the satellite data. In order to verify the impact of assigning countries/regions to subregions, these areas were removed from the mean weighted subregional $PM_{2.5}$ estimates. Estimates for 8 of the 14 subregions did not change. WPR-B, the subregion with the largest change after removal of these regions, only had an increase of $0.3\mu g/m^3$ for its $PM_{2.5\_Total}$ estimate and $0.2\mu g/m^3$ for its $PM_{2.5\_No\ Dust}$ estimate.

The estimated mean weighted subregional concentrations of fine particulate matter with and without the dust fraction included are presented in Table 6.1. For each $PM_{2.5}$ estimate, the population-weighted mean subregional concentrations were derived using 2005 country/region populations.

Table 6.1 Satellite derived mean weighted $PM_{2.5}$ concentrations and population coverage by World Health Organization (WHO) subregion

WHO Subregion	Countries With Satellite Data	2005 Population Represented by Satellite Data (millions)[a]	2005 Population Coverage (%)[b]	Mean Weighted $PM_{2.5\_Total}$ ($\mu g/m^3$)[c]	Mean Weighted $PM_{2.5\_No\ Dust}$ ($\mu g/m^3$)[d]
AFR-D	29	324	100	20.2	3.4
AFR-E	20	384	100	8.7	5.7
AMR-A	3	339	98	11.3	10.1
AMR-B	41	462	100	7.9	5.9
AMR-D	6	78	100	9.1	7.9
EMR-B	12	150	100	25.6	4.3
EMR-D	10	386	100	31.9	8.2
EUR-A	35	413	95	15.8	11.7
EUR-B	16	223	96	16.4	8.8
EUR-C	9	235	92	10.3	8.1
SEAR-B	3	306	99	13.1	11.5
SEAR-D	8	1,330	100	25.0	18.8
WPR-A	7	155	95	14.8	11.4
WPR-B	32	1,580	97	44.9	39.0
World	**231**	**6,360**	**98**	**24.7**	**18.0**

[a] 2005 country populations used to weight the mean $PM_{2.5}$ concentrations were aggregated at the subregional level

[b] Subregional percent coverage was obtained using estimated 2005 subregional populations in the denominator; estimated 2005 subregion populations were obtained using 2000 sugregional populations presented in the 2000 GBD(80) multiplied by 1.057 (assuming an annual growth rate of 1.14% per year over five years)

[c] Mean subregional $PM_{2.5}$ levels are weighted to 2005 country populations

[d] Values had dust (and sea salt) fraction removed and thus better represent $PM_{2.5}$ from combustion sources

For $PM_{2.5\_Total}$, the mean exposures in the most polluted subregions (WPR-B, EMR-B/D, and AFR-D) are 3 to 5 times higher than those in the least polluted subregions (AFR-E, and AMR-B/D). For $PM_{2.5\_No\ Dust}$, the mean exposures in the most polluted subregions (SEAR-D, WPR-B) are up to 11 times higher than those in the least polluted subregions (AFR-D and EMR-B). The world mean weighted $PM_{2.5\_Total}$ exposure was estimated to be 24.7$\mu g/m^3$, and $PM_{2.5\_No\ Dust}$ was estimated to be 18.0$\mu g/m^3$, representing approximately 98% of the global population.

Population coverage at the subregion-level was good, ranging from 92% to 100%. At the country-level, removal of countries with low population coverage did not alter the results.

When regions with a population coverage of <30% were excluded, the mean weighted subregional $PM_{2.5}$ concentrations remained exactly the same. Svalbard was removed from EUR-A, Maldives was removed from SEAR-D, and Fiji, Tokelau, and Tuvalu were removed from WPR-B.

The distribution of population according to estimated $PM_{2.5\_Total}$ ambient concentrations is shown in Figure 6.1. All countries in EMR-B and EUR-B had concentrations $\geq 10\mu g/m^3$. In contrast, all countries in AFR-E, AMR-A/B/D, EUR-C, SEAR-B, and WPR-A had $PM_{2.5}$ concentrations $\leq 20\mu g/m^3$, and those in EUR-A/B, and SEAR-D had concentrations of $\leq 30\mu g/m^3$.

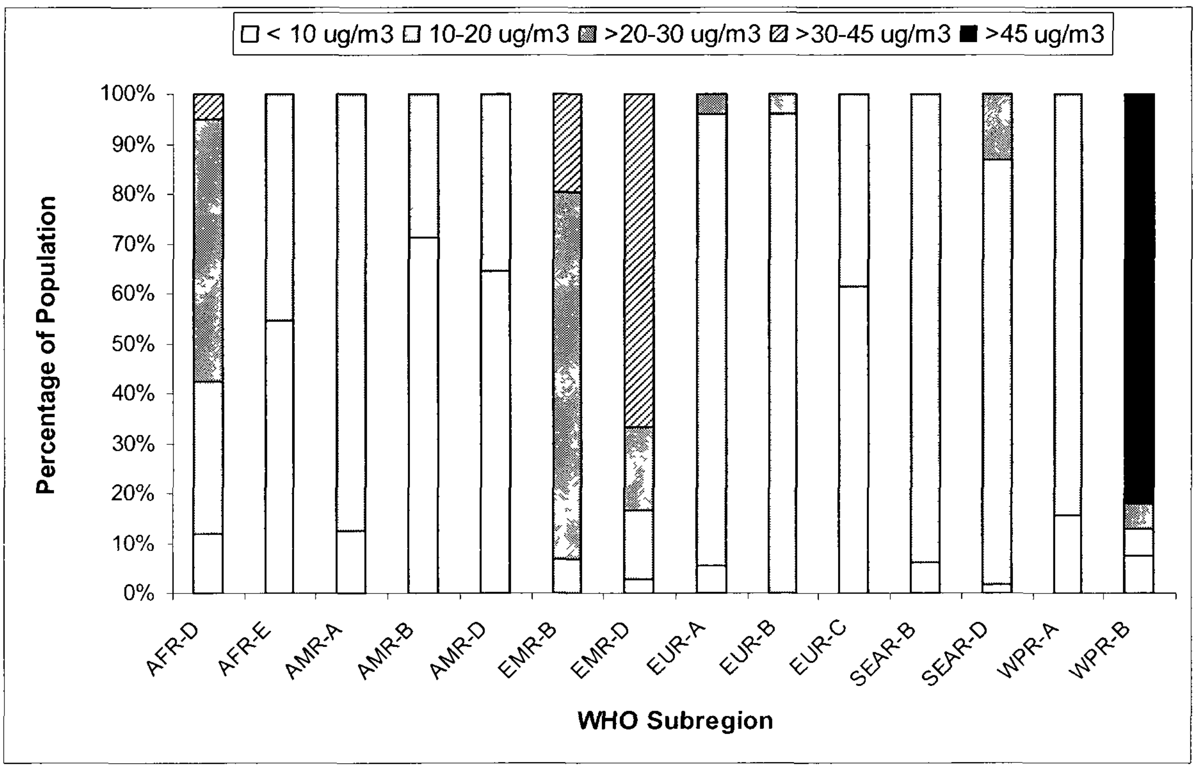

Figure 6.1 Population distribution according to estimated mean weighted country $PM_{2.5\_Total}$ ambient concentrations ($\mu g/m^3$), by subregion

The distribution of population according to estimated $PM_{2.5\_No\ Dust}$ ambient concentrations is shown in Figure 6.2. All countries in AMR-A and EUR-C had concentrations $\geq 5\mu g/m^3$. In contrast, all countries in AFR-E, AMR-A/B/D, EMR-D, and EUR-B/C had $PM_{2.5\_No\ Dust}$ concentrations $\leq 15\mu g/m^3$, and those in AFR-D, and EMR-B had concentrations of $\leq 10\mu g/m^3$.

As can be visualized in Figures 6.1 and 6.2, the subregions AFR-D, EMR-B and EMR-D presented with the greatest net difference in $PM_{2.5}$ values after removal of dust fractions.

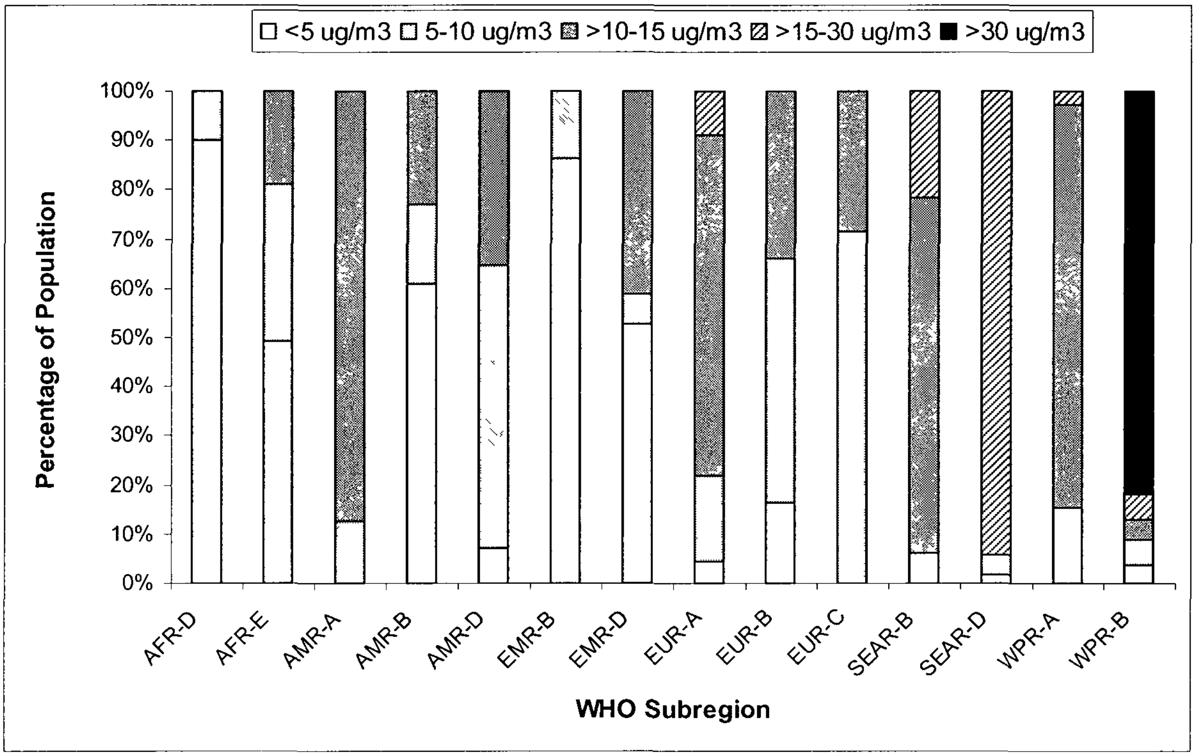

Figure 6.2 Population distribution according to estimated mean weighted country $PM_{2.5\_No\ Dust}$ ambient concentrations (µg/m³), by subregion

6.1.3 Comparison of $PM_{2.5}$ Estimates with the 2000 GBD for Urban Air Pollution

A comparison of the 2000 GBD baseline fine particulate matter estimates and those of the current study are shown in Table 6.2. Only the $PM_{2.5\_Total}$ values from this work were compared. Mean weighted global ambient $PM_{2.5}$ estimates are very close for the current analysis versus the previous GBD. In general, the satellite derived estimates of subregional fine particulate matter concentrations were lower than those presented in the 2000 GBD, with only EMR-B, EUR-A, and WPR-B subregions having higher satellite values. Half of the subregions (AMR-A, EMR-B, EUR-A/B/C, WPR-A/B) had absolute differences in mean weighted $PM_{2.5}$ values of less than 8ug/m³. Subregions with the largest differences include AMR-D, SEAR-B/D, EMR-D, with SEAR-B showing the largest discrepancy in $PM_{2.5}$ values, 40.9ug/m³ (122%). Overall, the range of absolute differences in mean weighted $PM_{2.5}$ concentrations was 0.4ug/m³ to 40.9ug/m³. The absolute difference in world $PM_{2.5}$

values was 5.3ug/m^3. The range of percent differences in mean weighted $PM_{2.5}$ concentrations was 1% to 122%, and the percent difference in world PM2.5 values was 19%.

In a sensitivity analysis, the 2000 GBD tested the assumption of the $PM_{2.5}$ to PM_{10} ratio. Areas affected by more crustal particles (i.e. dusty or desert areas) will have a greater proportion of PM_{10}, while areas with more anthropogenic sources of PM will have a larger proportion of $PM_{2.5}$. The study used a scaling factor of 0.65 for subregions AMR-A, EUR-A/B/C, and WPR-A, while a scaling factor of 0.35 was used for all other cities. Table 6.3 shows another comparison of $PM_{2.5}$ estimates between the two studies using the alternative approach to deriving $PM_{2.5}$ estimates from PM_{10} as discussed above. The world absolute difference, as well as percent difference increased slightly using this alternative approach; however, the differences vary in either direction at the subregional level. For example, the absolute difference in $PM_{2.5}$ estimates decreased in the alternative scenario for about half of the subregions (AFR-D/E, AMR-B/D, EMR-D, EUR-A, and SEAR-B/D), while it increased for the other 6 subregions.

Table 6.2 Comparison of population-weighted $PM_{2.5}$ values by subregion for the 2000 WHO Global Burden of Disease baseline assessment versus the current analysis

WHO Subregion	2000 WHO Global Burden of Disease Study			Current Analysis			Absolute Difference in $PM_{2.5}$ ($\mu g/m^3$)	Percent Difference in $PM_{2.5}$ Estimates (%)
	Cities in Subregion[a]	2000 Urban Population (millions)[b]	$PM_{2.5}$ ($\mu g/m^3$)[c]	Countries in Subregion	2005 Population Represented (millions)	$PM_{2.5\_Total}$ ($\mu g/m^3$)[d]		
AFR-D	107	67	34.0	29	325	20.2	13.8	51
AFR-E	105	68	19.5	20	384	8.7	10.8	76
AMR-A	267	232	12.5	3	339	11.3	1.3	11
AMR-B	399	217	18.5	41	462	7.9	10.6	80
AMR-D	47	30	25.5	6	78	9.1	16.4	95
EMR-B	89	57	20.0	12	150	25.6	5.6	24
EMR-D	126	99	55.0	10	386	31.9	23.1	53
EUR-A	429	162	13.0	35	413	15.8	2.8	19
EUR-B	182	82	24.0	16	223	16.4	7.6	38
EUR-C	275	109	15.5	9	235	10.3	5.2	40
SEAR-B	68	54	54.0	3	305	13.1	40.9	122
SEAR-D	356	214	42.0	8	1,330	25.0	17.0	51
WPR-A	242	100	16.0	7	155	14.8	1.2	8
WPR-B	519	528	44.5	32	1,580	44.9	0.4	1
Total	3211	2,020		231	6,370			
World			**30.0**			**24.7**	**5.3**	**19**

[a] Cities with population >100,000 and national capitals

[b] Population used in weighting $PM_{2.5}$ data; the total 2000 urban population was 2.0 billion, and the cities in study represent 70% of the urban population and 33% of global population

[c] The Global Model of Ambient Particulates (GMAPS) model developed at the World Bank was used to estimate concentrations of PM_{10} in cities and the average subregional concentrations; baseline $PM_{2.5}$ estimates were determined using a $PM_{2.5}$:PM_{10} ratio of 0.5

[d] Subregional $PM_{2.5}$ levels are population-weighted at the country and subregional levels; data was standardized to 35% relative humidity, and adjusted for sampling to better represent a true annual sample

Table 6.3 Comparison of population-weighted $PM_{2.5}$ values by subregion for the 2000 WHO Global Burden of Disease assessment for urban air pollution assuming an alternative $PM_{2.5}$:PM_{10} versus the current analysis

WHO Subregion	**2000 WHO Global Burden of Disease Study**			**Current Analysis**	**Absolute Difference in $PM_{2.5}$ ($\mu g/m^3$)**	**Percent Difference in $PM_{2.5}$ Estimates (%)**
	PM_{10} ($\mu g/m^3$)[a]	Ratio	$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5\_Total}$ ($\mu g/m^3$)[b]		
AFR-D	68	0.35	23.8	20.2	3.6	16
AFR-E	39	0.35	13.7	8.7	4.9	44
AMR-A	25	0.65	16.3	11.3	5.0	36
AMR-B	37	0.35	13.0	7.9	5.0	48
AMR-D	51	0.35	17.9	9.1	8.8	65
EMR-B	40	0.35	14.0	25.6	11.6	58
EMR-D	110	0.35	38.5	31.9	6.6	19
EUR-A	26	0.65	16.9	15.8	1.1	7
EUR-B	48	0.65	31.2	16.4	14.8	62
EUR-C	31	0.65	20.2	10.3	9.8	65
SEAR-B	108	0.35	37.8	13.1	24.7	97
SEAR-D	84	0.35	29.4	25.0	4.4	16
WPR-A	32	0.65	20.8	14.8	6.0	34
WPR-B	89	0.35	31.2	44.9	13.7	36
Total World	**60**		**30.6**	**24.7**	**5.9**	**21**

[a] The Global Model of Ambient Particulates (GMAPS) model developed at the World Bank was used to estimate concentrations of PM_{10} in cities and the average subregional concentrations

[b] Subregional $PM_{2.5}$ levels are the population-weighted at the country and subregional levels; data was standardized to 35% relative humidity, and adjusted for sampling to better represent a true annual sample

In the 2000 GBD for urban air pollution, correlations between predicted PM_{10} estimates and observed PM_{10} estimates were presented at the subregional level. Correlations were not presented for subregions for which there were no ground monitors (EMR-B), or which there were too few or no PM_{10} observations (AFR-D/E, EMR-D, EUR-C, SEAR-B). In general, subregions with fewer data points had lower correlations and were less precisely estimated.(80) Figures 6.3 and 6.4 indicate that as correlation decreases, discrepancy between the mean weighted subregional $PM_{2.5}$ estimates in this work and those of the 2000 GBD increases.

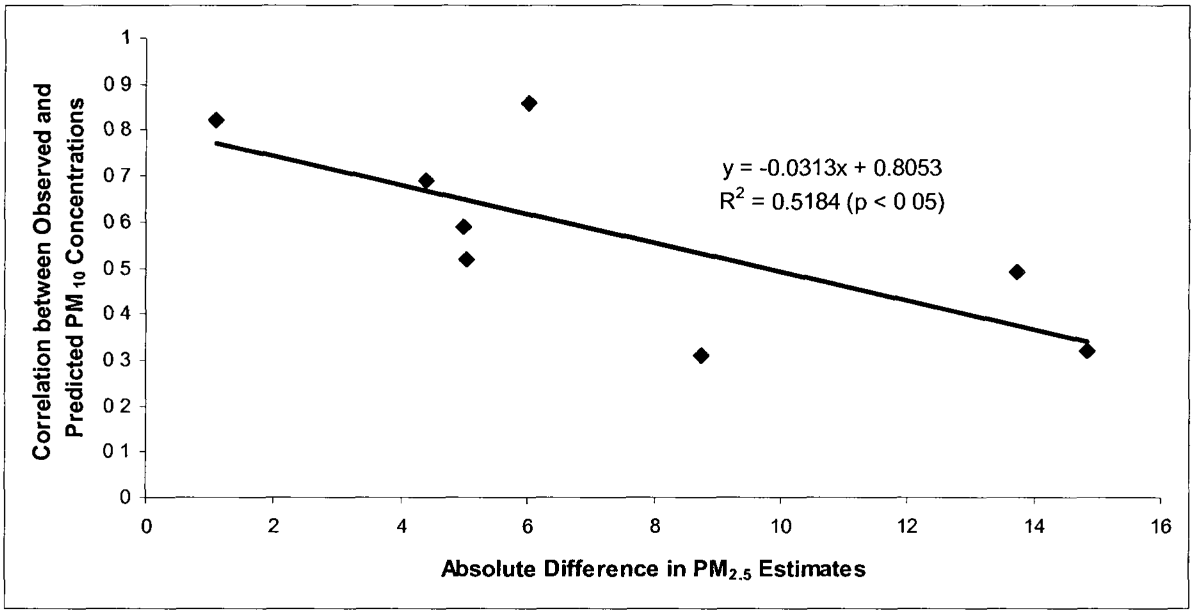

Figure 6.3 Correlation between observed and GMAPs predicted PM_{10} concentrations in the 2000 GBD for urban air pollution versus absolute differences in subregional $PM_{2.5}$ estimates between the 2000 GBD (baseline) and the current analysis for AMR-A/B/D, EUR-A/B, SEAR-D, and WPR-A/B

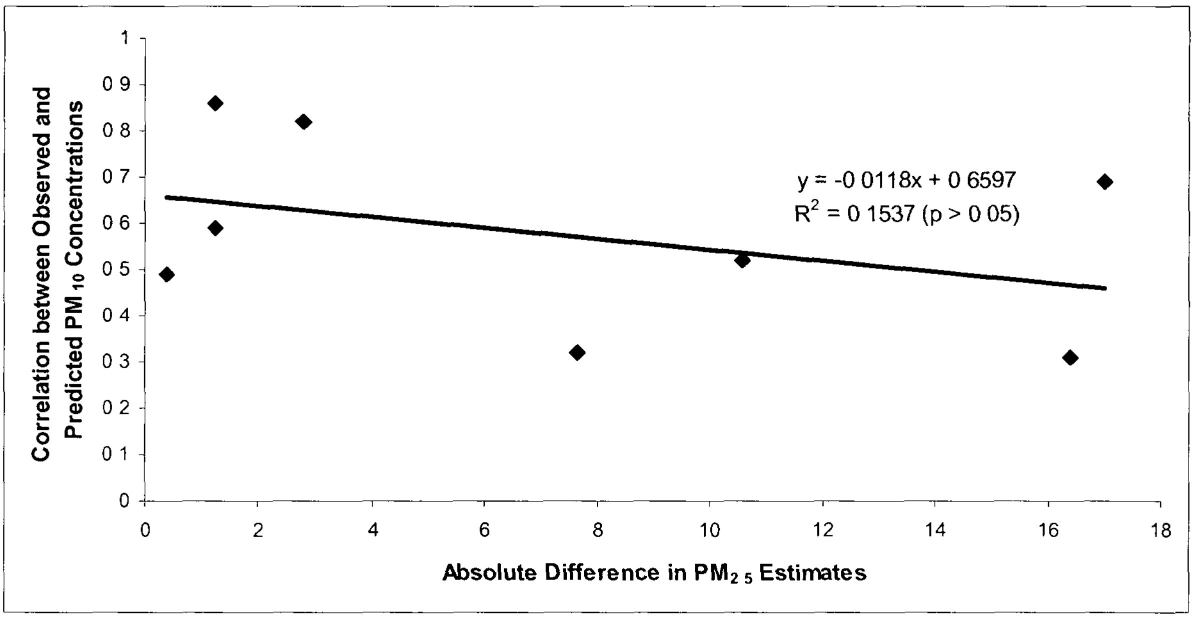

Figure 6.4 Correlation between observed and GMAPs predicted PM_{10} concentrations in the 2000 GBD versus absolute differences in subregional $PM_{2.5}$ estimates between the 2000 GBD (assuming alternative $PM_{2.5}$:PM_{10} ratio) and current analysis for AMR-A/B/D, EUR-A/B, SEAR-D, and WPR-A/B

All of the subregions for which correlation analysis was not possible due to inadequate observations of PM_{10} (AFR-D/E, EMR-B/D, EUR-C, SEAR-B) were in the upper 2/3 of subregions for which the greatest discrepancies exist. Furthermore, 2/3 of the subregions lacking correlation analysis were in the upper half of subregions with the greatest discrepancies.

The discrepancies in $PM_{2.5}$ estimates do not appear to be related to subregional population coverage of the satellite data. For instance, in the base case scenario, the subregions with the lowest satellite coverage, AMR-A, EUR-A/B/C, and WPR-A/B, had the smallest absolute differences (i.e. $<8ug/m^3$). Similarly, in the alternative scenario, the subregions with the largest discrepancies were not always the ones with the lowest coverage.

6.2 Mortality Data

6.2.1 Data Extraction

Of the 231 countries/regions with satellite data, 132 (57%) had detailed mortality data in the WHO Mortality Database. Of the remaining countries, 79 had some mortality data in the WHO Statistical Information System (WHOSIS), while 20 countries/regions had no mortality data. Appendix B provides information on mortality data sources available for each of the 231 countries with $PM_{2.5}$ exposure data.

Appendix C provides details on the mortality data for each of the 132 countries in the WHO Mortality Database, including the year of mortality data collected, the revision of ICD coding used, and the coverage for each country. Coverage was calculated by dividing total deaths reported for a country-year from the vital registration system by the total number of estimated deaths for that year for the national population.(83) Coverage ranged from 9% in Haiti to 100% in 36 other countries. Coverage data did not exist for approximately 20% of the countries.

6.2.2 Country and Subregional Mortality

The extracted number of deaths due to all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease were adjusted for coverage, and are presented at the country and subregional levels in Appendix D. Since only information on all cause mortality coverage was provided, it was assumed that coverage was similar for the other three air pollution causes of mortality. Mortality data for countries lacking information on coverage was not adjusted. Table 6.4 summarizes total subregional mortality for all four air pollution causes of mortality.

Table 6.4 Mortality from all cause, lung cancer, cardiopulmonary disease, and ischemic heart disease, by subregion and age

WHO Subregion	Number of Countries	All Cause Mortality[a]		Lung Cancer Mortality[a]		Cardiopulmonary Disease Mortality[a]		Ischemic Heart Disease Mortality[a]	
		All Ages	Adults	All Ages	Adults	All Ages	Adults	All Ages	Adults
AFR-D	5	17,185	15,017	279	279	6,787	6,420	1,687	1,685
AFR-E	2	780,027	661,455	6,049	6,043	201,831	190,953	16,396	16,341
AMR-A	3	2,761,873	2,703,144	181,588	181,580	1,201,518	1,198,279	501,838	501,764
AMR-B	41	2,864,135	2,593,207	53,228	53,108	1,034,863	1,010,204	279,824	279,479
AMR-D	5	300,768	244,300	3,042	3,010	89,446	78,176	13,243	13,144
EMR-B	5	127,709	84,124	854	848	30,874	24,777	5,573	5,129
EMR-D	2	456,020	367,461	1,622	1,573	183,899	150,945	11,663	11,309
EUR-A	26	4,016,136	3,978,499	209,492	209,468	1,809,125	1,807,010	577,232	577,180
EUR-B	16	1,573,765	1,480,834	53,391	53,301	921,699	895,050	286,270	286,165
EUR-C	9	3,704,486	3,639,514	88,074	88,047	2,241,215	2,235,743	1,134,309	1,134,138
SEAR-B	2	565,971	533,739	8,389	8,356	98,608	94,057	15,798	15,726
SEAR-D	1	1,494	1,338	8	8	156	152	20	20
WPR-A	5	1,264,052	1,253,451	71,860	71,855	559,715	558,549	111,630	111,606
WPR-B	10	1,518,993	1,399,188	64,523	64,438	671,707	646,285	119,179	118,898
TOTAL	**132**	**19,952,615**	**18,955,271**	**742,398**	**741,913**	**9,051,443**	**8,896,599**	**3,074,662**	**3,072,584**

[a] Mortality was extracted from the WHO mortality database and was adjusted for coverage

6.2.3 Comparison with the 2004 GBD Subregional Mortality Estimates

Tables 6.5 to 6.8 present subregional comparisons for all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortalities for the current analysis versus the WHO's 2004 update to the GBD project which modelled subregional mortality estimates.(90) Included in these tables is the proportion of countries in each subregion with coverage data in the current study. For half of the subregions, coverage data was available for all included countries (AFR-E, AMR-A/D, EUR-C, SEAR-B/D, WPR-A). Subregions EUR-A and EUR-B had coverage data for ≥95% of countries, while AFR-D, AMR-B, WPR-B had the lowest proportion of countries with coverage data at 40%, 61%, and 50% respectively.

Also shown in Tables 6.5-6.8 is the number of countries included in the subregional mortality estimates based on the 2004 WHO GBD update versus those derived from the WHO Mortality Database (MDB). The number of countries was the same for four subregions (AMR-A, EUR-B/C, and WPR-A). For three subregions (AMR-D, EUR-A, and SEAR-B), there was 1 country missing from subregional mortality estimates derived from the WHO MDB. Large differences in the number of countries included in the subregional estimates were noted for AFR-D/E, EMR-B/D, SEAR-D, and WPR-B, where the WHO GBD update included between 7 and 21 more countries per subregion in their mortality estimates compared to this assessment. AMR-B had more countries included in the mortality estimates provided in this work than were included in the WHO 2004 update. There were 15 small island states that had satellite derived $PM_{2.5}$ exposure data as well as mortality data, and they were included in the analysis. AMR-B has highly comparable mortality estimates between the two sources.

Mortality data was comparable for all cause, lung cancer, and cardiopulmonary mortality across the subregions AMR-A/B, EUR-A/C, and WPR-A, such that the percent differences in mortality estimated from the WHO GBD update versus those derived from the WHO MDB were small or even negligible. Percent differences for these subregions ranged from <1 to 6% for these three outcomes. The other 9 subregions had moderate to high percent differences in mortality estimates, with the highest differences observed for AFR-D and SEAR-D. Percent differences for ischemic heart disease were higher for all subregions.

Overall, world estimates of mortality derived in this thesis represented 34%, 39%, 56%, and 48%, of all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortalities estimated in the WHO GBD 2004 update.

Table 6.5 Comparison of subregional all cause (AC) mortality in all ages as estimated in the WHO GBD update versus that derived from the WHO Mortality Database

WHO Subregion	Number of Countries Included in the GBD Update	Number of Countries in Current Analysis	Proportion with Coverage Data (%)[a]	2004 AC Mortality[b]	AC Mortality for Current Analysis[c]	Absolute Difference in Mortality	Percent Difference in Mortality (%)
AFR D	26	5	40	5,086,752	17,185	5,069,567	100
AFR E	20	2	100	6,161,388	780,027	5,381,361	87
AMR A	3	3	100	2,774,561	2,761,873	12,688	0
AMR B	26	41	61	2,855,541	2,864,135	8,594	0
AMR D	6	5	100	528,139	300,768	227,371	43
EMR B	12	5	40	705,921	127,709	578,212	82
EMR D	9	2	50	3,600,340	456,020	3,144,320	87
EUR A	27	26	96	3,968,296	4,016,136	47,840	1
EUR B	16	16	94	1,896,593	1,573,765	322,828	17
EUR C	9	9	100	3,628,084	3,704,486	76,402	2
SEAR B	3	2	100	2,740,864	565,971	2,174,893	79
SEAR D	8	1	100	12,538,614	1,494	12,537,120	100
WPR A	5	5	100	1,195,942	1,264,052	68,110	6
WPR B	22	10	50	10,995,450	1,518,993	9,476,457	86
Total[d]	**192**	**132**		**58,676,485**	**19,952,614**	**39,125,763**	67
World[e]				**58,771,791**			

[a] Proportion of countries in the current analysis with coverage data
[b] From the WHO GBD update of 2004 modelled mortality estimates
[c] Mortality was extracted from the WHO mortality database and was adjusted for coverage
[d] Sum of subregional mortalities for *included* member states
[e] World estimate included populations living outside WHO member states

Table 6.6 Comparison of subregional cardiopulmonary disease (CPD) mortality in all ages as estimated in the WHO GBD update versus that derived from the WHO Mortality Database

WHO Subregion	Number of Countries Included in the GBD Update	Number of Countries in Current Analysis	Proportion with Coverage Data (%)[a]	2004 CPD Mortality[b]	CPD Mortality for Current Analysis[c]	Absolute Difference in Mortality	Percent Difference in Mortality (%)
AFR D	26	5	40	1,467,729	6,787	1,460,942	100
AFR E	20	2	100	1,441,032	201,831	1,239,201	86
AMR A	3	3	100	1,277,033	1,201,518	75,515	6
AMR B	26	41	61	1,041,101	1,034,863	6,238	1
AMR D	6	5	100	144,690	89,446	55,244	38
EMR B	12	5	40	303,890	30,874	273,016	90
EMR D	9	2	50	1,274,295	183,899	1,090,396	86
EUR A	27	26	96	1,925,731	1,809,125	116,606	6
EUR B	16	16	94	1,002,130	921,699	80,431	8
EUR C	9	9	100	2,271,781	2,241,215	30,566	1
SEAR B	3	2	100	894,622	98,608	796,014	89
SEAR D	8	1	100	5,020,506	156	5,020,350	100
WPR A	5	5	100	553,674	559,715	6,041	1
WPR B	22	10	50	5,386,781	671,707	4,715,074	88
Total[d]	**192**	**132**		**24,004,996**	**9,051,443**	**14,965,634**	**62**
World[e]				**22,923,923**			

[a] Proportion of countries in the current analysis with coverage data
[b] From the WHO GBD update of 2004 mortality estimates
[c] Mortality was extracted from the WHO mortality database and was adjusted for coverage
[d] Sum of subregional mortalities for *included* member states
[e] World estimate included populations living outside WHO member states

Table 6.7 Comparison of subregional lung cancer (LC) mortality in all ages as estimated in the WHO GBD update versus that derived from the WHO Mortality Database

WHO Subregion	Number of Countries Included in the GBD Update	Number of Countries in Current Analysis	Proportion with Coverage Data (%)[a]	2004 LC Mortality[b]	LC Mortality for Current Analysis[c]	Absolute Difference in Mortality	Percent Difference in Mortality (%)
AFR D	26	5	40	11,015	279	10,736	97
AFR E	20	2	100	13,777	6,049	7,728	56
AMR A	3	3	100	185,993	181,588	4,405	2
AMR B	26	41	61	53,555	53,228	327	1
AMR D	6	5	100	4,436	3,042	1,394	31
EMR B	12	5	40	7,460	854	6,606	89
EMR D	9	2	50	25,076	1,622	23,454	94
EUR A	27	26	96	215,137	209,492	5,645	3
EUR B	16	16	94	69,532	53,391	16,141	23
EUR C	9	9	100	86,089	88,074	1,985	2
SEAR B	3	2	100	51,124	8,389	42,735	84
SEAR D	8	1	100	103,182	8	103,174	100
WPR A	5	5	100	70,039	71,860	1,821	3
WPR B	22	10	50	425,274	64,523	360,751	85
Total[d]	**192**	**132**		**1,321,689**	**742,399**	**586,902**	**44**
World[e]				**1,323,218**			

[a] Proportion of countries in the current analysis with coverage data
[b] From the WHO GBD update of 2004 mortality estimates
[c] Mortality was extracted from the WHO mortality database and was adjusted for coverage
[d] Sum of subregional mortalities for *included* member states
[e] World estimate included populations living outside WHO member states

Table 6.8 Comparison of subregional ischemic heart disease (IHD) mortality in all ages as estimated in the WHO GBD update versus that derived from the WHO Mortality Database

WHO Subregion	Number of Countries Included in the GBD Update	Number of Countries in Current Analysis	Proportion with Coverage Data (%)[a]	2004 IHD Mortality[b]	IHD Mortality for Current Analysis[c]	Absolute Difference in Mortality	Percent Difference in Mortality (%)
AFR D	26	5	40	170,448	1,687	168,761	99
AFR E	20	2	100	175,305	16,396	158,909	91
AMR A	3	3	100	548,541	501,838	46,703	9
AMR B	26	41	61	345,789	279,824	65,965	19
AMR D	6	5	100	31,015	13,243	17,772	57
EMR B	12	5	40	145,064	5,573	139,491	96
EMR D	9	2	50	433,924	11,663	422,261	97
EUR A	27	26	96	659,552	577,232	82,320	12
EUR B	16	16	94	448,691	286,270	162,421	36
EUR C	9	9	100	1,187,335	1,134,309	53,026	4
SEAR B	3	2	100	277,031	15,798	261,233	94
SEAR D	8	1	100	1,733,530	20	1,733,510	100
WPR A	5	5	100	131,090	111,630	19,460	15
WPR B	22	10	50	898,037	119,179	778,858	87
Total[d]	**192**	**132**		**7,185,352**	**3,074,662**	**4,110,690**	**57**
World[e]				**6,436,826**			

[a] Proportion of countries in the current analysis with coverage data
[b] From the WHO GBD update of 2004 mortality estimates
[c] Mortality was extracted from the WHO mortality database and was adjusted for coverage
[d] Sum of subregional mortalities for *included* member states
[e] World estimate included populations living outside WHO member states

6.2.4 Issues Surrounding All Cause Mortality

Four subregions (AMR-A, EUR-A, EMR-D, WPR-A) had 100% of included countries with similar proportions of all cause mortalities due to cardiopulmonary disease. Two subregions, AMR-B and WPR-B, had 83% and 70% respectively of countries with similar proportions to the U.S., while AFR-D, AMR-D, and EUR-C all had 60% of included countries with similar proportions. AFR-D, SEAR-B/D had no included countries with proportions similar to the U.S. population. Proportions were considered to be similar to those of the U.S. if they were within a 10 percent range across the two age categories, all ages and adults. Appendix E shows the proportions for each country across two age categories, and compares them to those of the U.S. population.

6.3 Global Assessment of Mortality Attributable to $PM_{2.5}$

6.3.1 Base Case Scenario

Subregional relative risks calculated under the base case scenario are presented in Table 6.9 for all four causes of mortality of interest, for the total as well as anthropogenic components of $PM_{2.5}$.

Table 6.9 Relative risks of all cause (RR_{AC}), cardiopulmonary disease (RR_{CPD}), lung cancer (RR_{LC}), and ischemic heart disease (RR_{IHD}) mortalities associated with $PM_{2\,5\_Total}$ and $PM_{2\,5\_No\ Dust}$, under the base case scenario, by subregion (95% confidence intervals)

WHO Subregion	**RR_{AC}**		**RR_{CPD}**		**RR_{LC}**		**RR_{IHD}**	
	$PM_{2\,5\_Total}$	$PM_{2\,5\_No\ Dust}$	$PM_{2\,5\_Total}$	$PM_{2\,5\_No\ Dust}$	$PM_{2\,5\_Total}$	$PM_{2\,5\_No\ Dust}$	$PM_{2\,5\_Total}$	$PM_{2\,5\_No\ Dust}$
AFR-D	1.02 (1.01-1.04)	1.00 (1.00-1.00)	1.04 (1.02-1.06)	1.00 (1.00-1.00)	1.04 (1.02-1.07)	1.00 (1.00-1.00)	1.08 (1.05-1.12)	1.00 (1.00-1.00)
AFR-E	1.01 (1.00-1.01)	1.00 (1.00-1.00)	1.01 (1.01-1.01)	1.00 (1.00-1.00)	1.01 (1.00-1.01)	1.00 (1.00-1.00)	1.02 (1.01-1.02)	1.00 (1.00-1.00)
AMR-A	1.04 (1.02-1.06)	1.03 (1.02-1.05)	1.07 (1.04-1.10)	1.05 (1.03-1.07)	1.08 (1.03-1.12)	1.07 (1.02-1.09)	1.15 (1.09-1.20)	1.11 (1.07-1.16)
AMR-B	1.02 (1.01-1.03)	1.01 (1.01-1.02)	1.03 (1.02-1.04)	1.02 (1.01-1.03)	1.04 (1.01-1.06)	1.03 (1.01-1.04)	1.07 (1.04-1.09)	1.04 (1.03-1.06)
AMR-D	1.03 (1.02-1.04)	1 02 (1.01-1.03)	1.05 (1.03-1.06)	1.03 (1.02-1.04)	1.05 (1.02-1.08)	1.04 (1.01-1.06)	1.10 (1.06-1.14)	1.07 (1.04-1.09)
EMR-B	1.15 (1.08-1.23)	1.00 (1.00-1.00)	1.25 (1.15-1.37)	1.00 (1.00-1.00)	1.28 (1.11-1.48)	1.00 (1.00-1.00)	1.60 (1.36-1.89)	1.00 (1.00-1.01)
EMR-D	1.28 (1.15-1.42)	1 05 (1.03-1.07)	1.48 (1.27-1.72)	1.07 (1.05-1.10)	1.54 (1.20-1.98)	1.08 (1.03-1.13)	2.27 (1.70-3.02)	1.16 (1.10-1.23)
EUR-A	1.08 (1.04-1.11)	1.04 (1.02-1.07)	1.12 (1.07-1.18)	1.07 (1.04-1.10)	1.14 (1.06-1.23)	1.08 (1.03-1.13)	1.28 (1.17-1.39)	1.16 (1.10-1.22)
EUR-B	1.08 (1.05-1.12)	1.02 (1.01-1.04)	1.14 (1.08-1.19)	1.04 (1.02-1.05)	1.15 (1.06-1.25)	1.04 (1.02-1.07)	1.31 (1.19-1.43)	1.08 (1.05-1.11)
EUR-C	1.03 (1.02-1.05)	1.02 (1.01-1.03)	1.06 (1.03-1.08)	1.03 (1.02-1.04)	1.06 (1.03-1.10)	1.03 (1.01-1.05)	1.12 (1.08-1.17)	1.06 (1.04-1.08)
SEAR-B	1.07 (1.04-1.11)	1.06 (1.03-1.09)	1.12 (1.07-1.17)	1.09 (1.06-1.13)	1.13 (1.05-1.22)	1.11 (1.04-1.17)	1.26 (1.16-1.37)	1.21 (1.13-1.29)
SEAR-D	1.01 (1.00-1.01)	1.00 (1.00-1.00)	1.01 (1.01-1.01)	1.00 (1.00-1.00)	1.01 (1.00-1.02)	1.00 (1.00-1.00)	1.02 (1.01-1.03)	1.00 (1.00-1.00)
WPR-A	1.07 (1.04-1.11)	1.05 (1.03-1.07)	1.12 (1.07-1.17)	1.08 (1.05-1.11)	1.13 (1.05-1.22)	1.08 (1.03-1.14)	1.26 (1.16-1.37)	1.17 (1.11-1.23)
WPR-B	1.37 (1.19-1.57)	1.30 (1.16-1.47)	1.65 (1.36-2.00)	1.53 (1.30-1.80)	1.73 (1.26-2.39)	1.60 (1.22-2.10)	2.85 (1.97-4.12)	2.43 (1.78-3.33)

Figures 6.5 and 6.6 show the subregional relative risk estimates under the base case scenario for all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortalities associated with $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$. As expected, based on the values of risk coefficients, ischemic heart disease mortality had the largest relative risk estimates for both $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$, and all cause mortality had the smallest risk estimates.

Subregions WPR-B, EMR-D, and EMR-B have respectively the highest relative risk estimates for all 4 causes of death for $PM_{2.5\_Total}$. However, once the dust component of $PM_{2.5}$ is removed, the relative risk estimates for EMR-B and EMR-D become comparable to estimates for other subregions, while those of WPR-B remain larger for all 4 scenarios involving $PM_{2.5\_No\ Dust}$.

Countries in the Mediterranean regions (EMR-D) had large dust components and were associated with large decreases in ambient $PM_{2.5}$ values with removal of the dust component. The relative risks of all cause, cardiopulmonary, lung cancer, and ischemic heart disease mortality decreased by 18%, 28%, 30% and 49% respectively for EMR-D when the dust component was removed from the base case scenario. The decrease in relative risk estimates associated with the removal of the dust component of $PM_{2.5}$ is largest for ischemic heart disease.

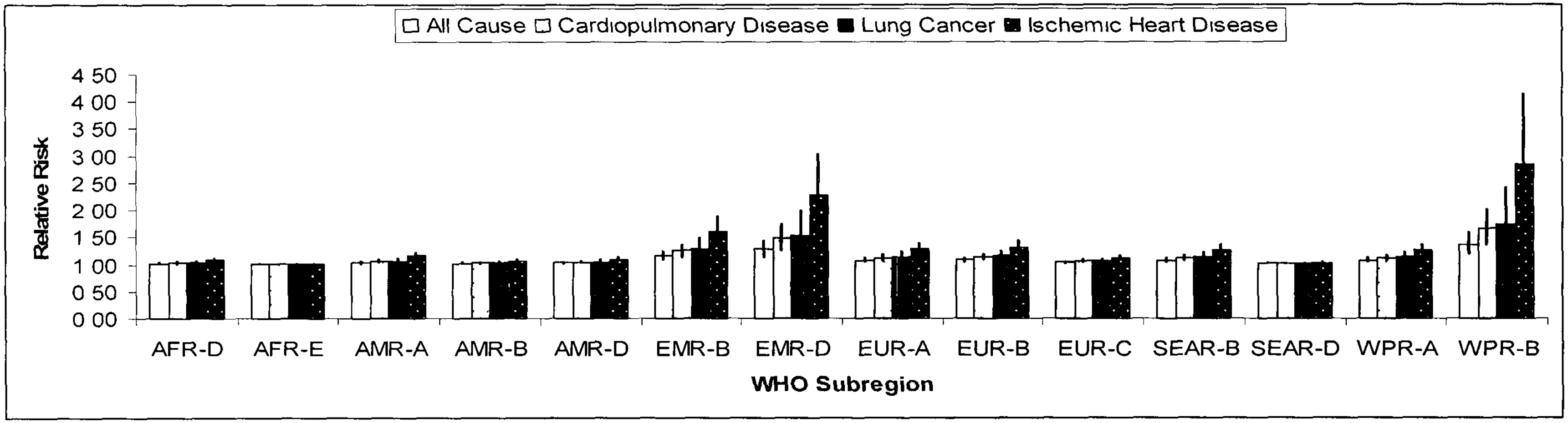

Figure 6.5 Relative risk estimates under the base case scenario for all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortalities associated with $PM_{2\ 5\_Total}$, by subregion

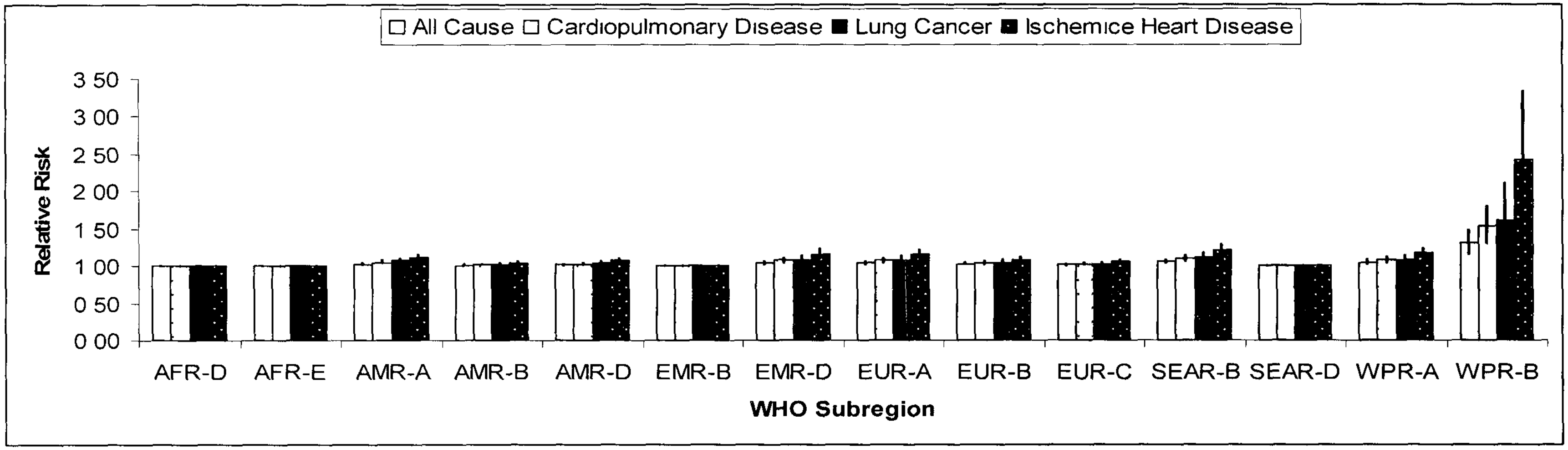

Figure 6.6 Relative risk estimates under the base case scenario for all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortalities associated with $PM_{2\ 5\_No\ Dust}$, by subregion

Table 6.10 Attributable fractions of adult all cause mortality (AF_{AC}), cardiopulmonary disease (AF_{CPD}), lung cancer (AF_{LC}), and ischemic heart disease (AF_{IHD}) associated with $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ under the base case, by subregion (95% confidence intervals)

WHO Subregion	**AF_{AC}**		**AF_{CPD}**		**AF_{LC}**		**AF_{IHD}**	
	$PM_{2.5\_Total}$	$PM_{2.5\_No\ Dust}$	$PM_{2.5\_Total}$	$PM_{2.5\_No\ Dust}$	$PM_{2.5\_Total}$	$PM_{2.5\_No\ Dust}$	$PM_{2.5\_Total}$	$PM_{2.5\_No\ Dust}$
AFR-D	1.0 (0.6-1.4)	0.0 (0.0-0.0)	1.2 (0.7-1.6)	0.0 (0.0-0.0)	0.8 (0.3-1.1)	0.0 (0.0-0.0)	0.4 (0.3-0.5)	0.0 (0.0-0.0)
AFR-E	0.6 (0.4-0.9)	0.0 (0.0-0.0)	1.0 (0.6-1.4)	0.0 (0.0-0.0)	1.1 (0.5-1.8)	0.0 (0.0-0.0)	2.2 (1.4-2.9)	0.0 (0.0-0.0)
AMR-A	4.0 (2.3-5.8)	3.2 (1.8-4.6)	6.4 (4.0-8.7)	5.0 (3.1-6.9)	7.0 (3.0-10.9)	5.5 (2.4-8.6)	12.9 (8.5-17.0)	10.3 (6.8-13.6)
AMR-B	1.6 (0.9-2.3)	1.0 (0.6-1.4)	2.3 (1.4-3.1)	1.3 (0.8-1.8)	2.5 (1.0-3.8)	1.3 (0.6-2.1)	5.9 (3.9-7.7)	3.4 (2.3-4.5)
AMR-D	2.7 (1.5-3.9)	2.1 (1.2-3.0)	4.3 (2.7-5.9)	3.3 (2.1-4.6)	5.3 (2.2-8.2)	4.3 (1.8-6.7)	7.8 (5.1-10.3)	6.0 (4.0-8.0)
EMR-B	13.8 (8.0-19.3)	0.2 (0.1-0.3)	21.3 (13.8-28.2)	0.2 (0.1-0.3)	23.2 (10.5-34.0)	0.1 (0.0-0.1)	43.1 (30.7-53.1)	0.9 (0.6-1.2)
EMR-D	18.9 (11.1-26.2)	0.0 (0.0-0.0)	28.6 (18.7-37.3)	0.0 (0.0-0.0)	31.0 (14.3-44.4)	0.0 (0.0-0.0)	50.6 (36.6-61.5)	0.2 (0.2-0.3)
EUR-A	7.0 (4.0-9.9)	4.3 (2.4-6.1)	11.0 (6.9-14.9)	6.8 (4.3-9.3)	12.2 (5.3-18.6)	7.7 (3.3-11.8)	21.5 (14.5-27.8)	14.1 (9.4-18.5)
EUR-B	7.4 (4.2-10.6)	3.2 (1.8-4.6)	11.6 (7.3-15.7)	4.8 (3.0-6.6)	12.4 (5.4-18.9)	7.3 (3.1-11.2)	23.1 (15.6-29.8)	8.6 (5.7-11.3)
EUR-C	3.3 (1.9-4.7)	1.7 (1.0-2.5)	5.3 (3.3-7.2)	2.8 (1.7-3.8)	6.0 (2.6-9.3)	3.3 (1.4-5.1)	11.1 (7.4-14.7)	6.2 (4.1-8.3)
SEAR-B	6.7 (3.8-9.4)	5.4 (3.1-7.7)	9.1 (5.8-12.3)	7.3 (4.6-10.0)	13.6 (5.9-20.6)	11.4 (4.9-17.4)	17.5 (11.9-22.6)	14.2 (9.6-18.5)
SEAR-D	0.6 (0.3-0.9)	0.0 (0.0-0.0)	1.0 (0.6-1.3)	0.0 (0.0-0.0)	1.1 (0.4-1.7)	0.0 (0.0-0.0)	2.0 (1.3-2.7)	0.0 (0.0-0.0)
WPR-A	6.9 (3.9-9.8)	4.6 (2.6-6.6)	10.8 (6.8-14.6)	7.2 (4.5-9.9)	11.9 (5.2-18.1)	8.0 (3.4-12.4)	17.4 (11.8-22.5)	12.1 (8.0-15.8)
WPR-B	17.6 (10.5-23.9)	14.9 (8.8-20.4)	28.4 (19.1-36.2)	24.5 (16.3-31.5)	33.3 (16.1-46.0)	28.9 (13.7-40.6)	43.8 (33.0-51.6)	38.4 (28.5-45.7)
World	6.6 (3.8-9.2)	2.9 (1.7-4.1)	10.2 (6.6-13.5)	4.5 (2.9-6.0)	11.5 (5.2-17.0)	5.6 (2.5-8.3)	18.5 (13.0-23.2)	8.2 (5.6-10.4)

Table 6.10 displays subregional and world attributable fractions of adult all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortalities due to $PM_{2.5}$ under the base case scenario. The estimates were derived based on 132 countries with $PM_{2.5}$ and mortality data, and the adult population was defined as those ≥20 years of age.

Under the base case scenario, the global fraction of mortality attributable to $PM_{2.5\_Total}$ was 6.6% (95% confidence interval: 3.8-9.2) for all causes, 10.2% (6.6-13.5) for cardiopulmonary disease, 11.5% (5.2-17.0) for lung cancer, and 18.5% (13.0-23.2) for ischemic heart disease. The global fraction of mortality attributable to $PM_{2.5\_No\ Dust}$ was 2.9% (1.7-4.1) for all causes, 4.5% (2.9-6.0) for cardiopulmonary disease, 5.6% (2.5-8.3) for lung cancer, and 8.2% (5.6-10.4) for ischemic heart disease. Risk coefficients for the association between $PM_{2.5}$ and mortality follow the same trend, and are lowest for all cause mortality, followed by cardiopulmonary disease, lung cancer, and ischemic heart disease mortalities.

The attributable fraction estimates associated with the anthropogenic component of $PM_{2.5}$ were roughly 50% lower than those associated with total component of $PM_{2.5}$ Decreases in AF estimates were largest for the Mediterranean regions (EMR), with decreases being slightly greater for subregion EMR-D compared to EMR-B, and were smallest for the African (AFR) subregions as well as for the Americas (AMR).

Overall, the Eastern Mediterranean and Western Pacific subregions had the largest attributable fractions of mortality associated with $PM_{2.5}$, while the African subregions had the smallest. The mortality attributable to $PM_{2.5}$ for the two Mediterranean subregions, EMR-B and EMR-D, was predominately related to the non-anthropogenic component of $PM_{2.5}$, while the AF of mortality associated with $PM_{2.5}$ in the Western Pacific subregions was predominantly associated with the anthropogenic component. WPR-B, which was associated with the highest attributable fractions of mortality for all causes, contributed greatly to global estimates of mortality associated with $PM_{2.5}$. Removal of this subregion from the analysis decreased base case world estimates of mortality by 14% for all cause mortality, 15% for cardiopulmonary disease and lung cancer mortalities, and 10% for ischemic heart disease mortality.

6.3.2 Sensitivity Analyses

Alternative concentration-response curves for all cause mortality associated with $PM_{2.5}$ for 231 countries under all sensitivity analyses are presented in Figures 6.7 and 6.8 for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ respectively. Relative risk estimates are increased for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ under the linear and log-linear scenarios when the reference value is decreased. The difference in relative risk estimates between the two reference values is larger for $PM_{2.5\_No\ Dust}$ and for the log-linear C-R functions compared to the linear functions. The log-linear risk estimates for both $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ are substantially larger than those derived from the linear function, particularly at lower concentrations. The shape of the log-linear function is such that risk increases in larger intervals at lower concentrations while allowing for a more gradual increase in risk at higher $PM_{2.5}$ concentrations. Setting a maximum exposure threshold of $30\mu g/m^2$ maximizes the relative risk of all cause mortality at 1.2, while maximizing the exposure at the intersection of the hybrid models only slightly decreases the relative risk for a few countries with concentrations of $PM_{2.5\_Total}$ greater than $50\mu g/m^2$. The C-R function trends observed for all cause mortality under all 10 scenarios are the same for all four air pollution causes of mortality.

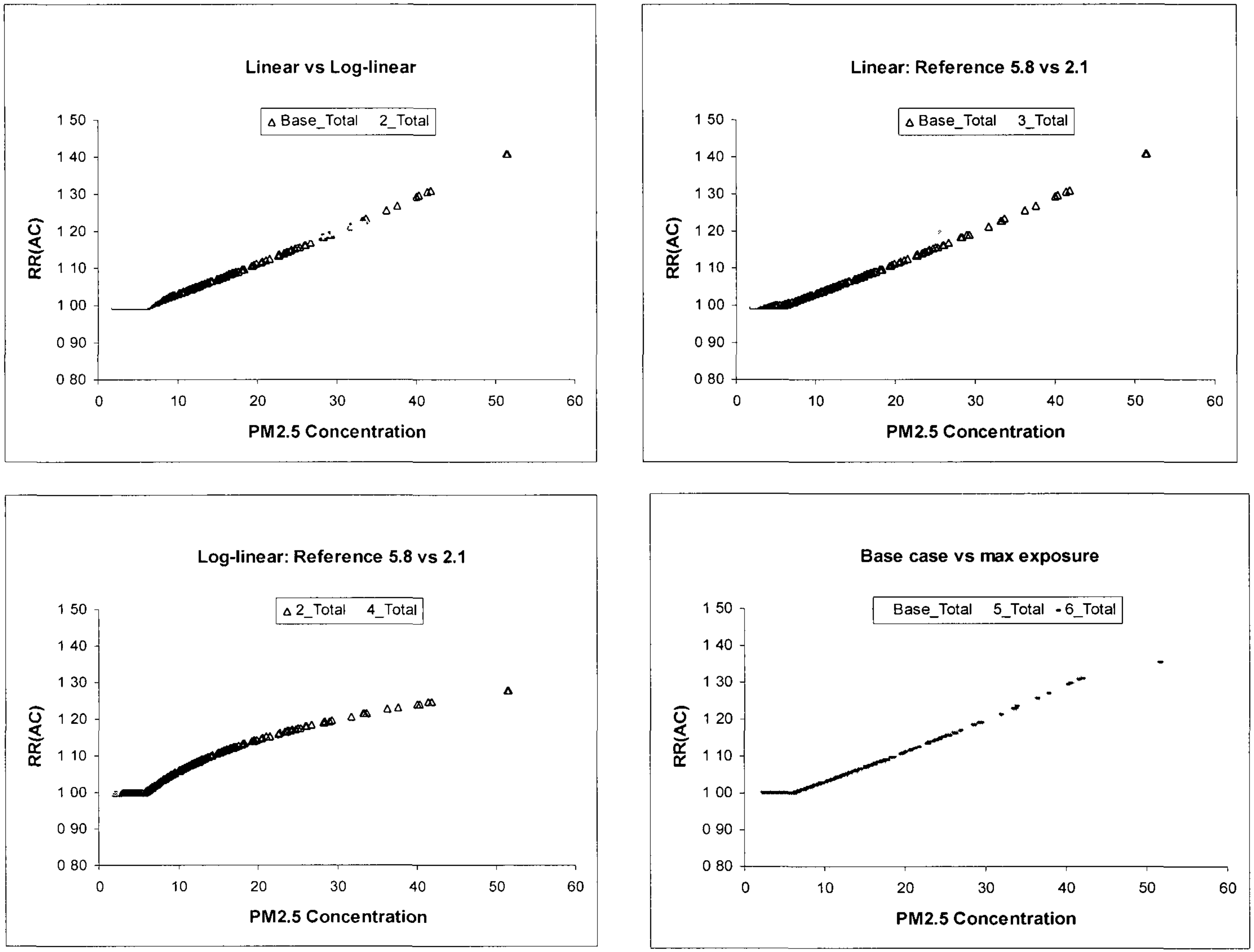

Figure 6.7 Alternative concentration-response curves for all cause mortality associated with $PM_{2\ 5\_Total}$ for 231 countries

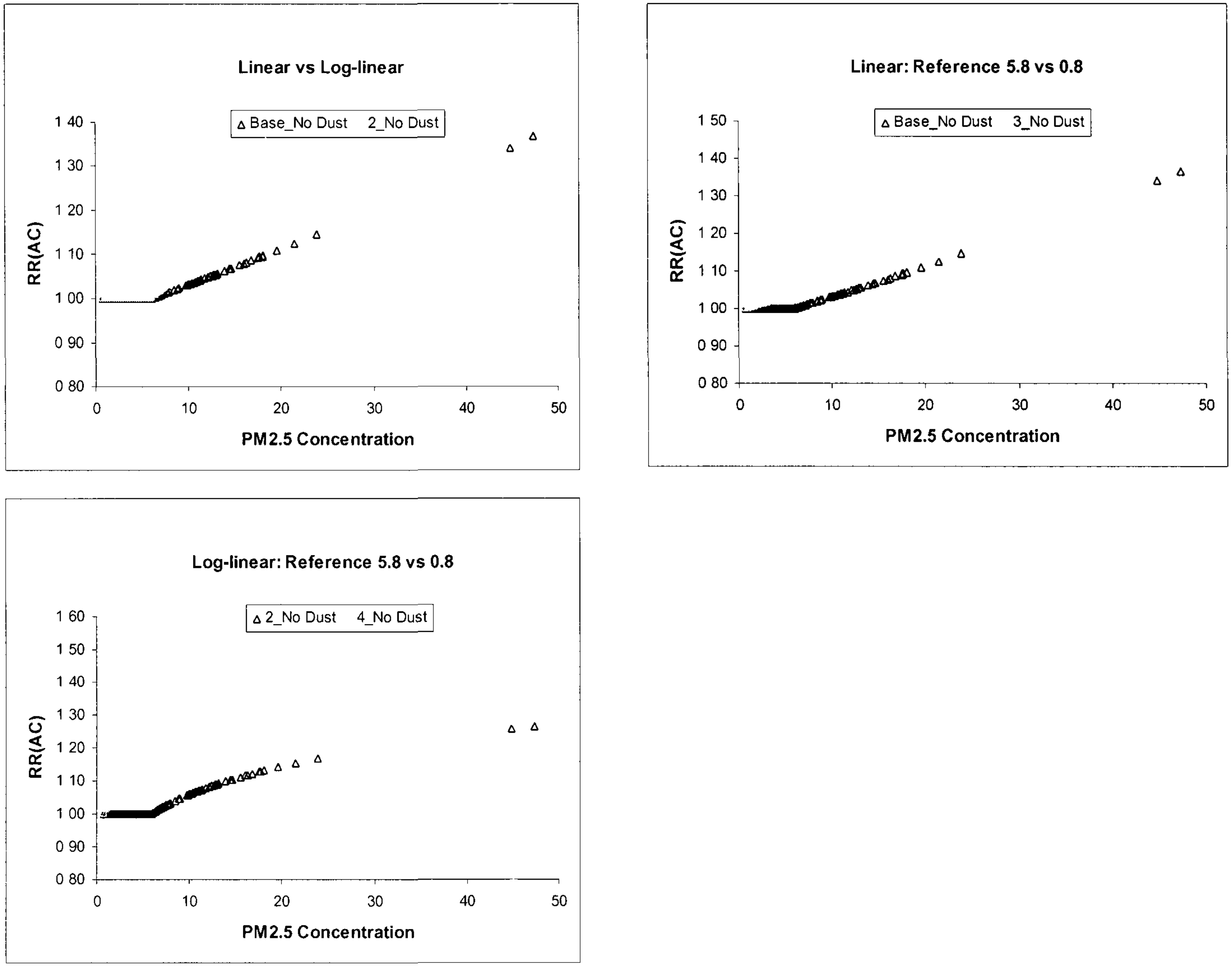

Figure 6.8 Alternative concentration-response curves for all cause mortality associated with $PM_{2\ 5\_No\ Dust}$ for 231 countries

Subregional relative risks calculated for all sensitivity scenarios are presented in Appendix F for all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortalities.

Tables 6.11-6.14 display subregional and world attributable fractions of adult mortality due to $PM_{2.5}$ under all sensitivity scenarios for all causes of mortality of interest. The estimates were derived based on 132 countries with $PM_{2.5}$ and mortality data, and the adult population was defined as those ≥20 years of age.

Table 6 11 Attributable fractions of adult all cause mortality (AF_{AC}) associated with $PM_{2 5}$ (95% CIs)

WHO Subregion	AF_{AC} associated with $PM_{2 5}$							
	Selection of C-R function		**Theoretical minimum**				**Maximum exposure threshold**	
	Scenario 2_{Total} Log-linear, Ref 5 8	Scenario $2_{No Dust}$ Log-linear, Ref 5 8	Scenario $3_{\_Total}$ Linear, Ref 2 1	Scenario $3_{\_No Dust}$ Linear, Ref 0 8	Scenario 4_{Total} Log-linear, Ref 2 1	Scenario $4_{No Dust}$ Log-linear, Ref 0 8	Scenario 5 Linear, Ref 5 8, Max 30	Scenario 6 Linear, Ref 5 8, Max Hybrid
AFR-D	1 2 (0 7-1 6)	0 0 (0 0-0 0)	2 0 (1 1-2 8)	0 3 (0 2-0 5)	5 1 (3 2-7 0)	2 3 (1 5-3 3)	1 0 (0 6-1 4)	1 0 (0 6-1 4)
AFR-E	1 4 (0 9-2 0)	0 0 (0 0-0 0)	3 3 (1 9-4 8)	3 6 (2 0-5 1)	10 2 (6 4-13 9)	14 5 (9 2-19 6)	0 6 (0 4-0 9)	0 6 (0 4-0 9)
AMR-A	6 8 (4 3-9 4)	5 7 (3 5-7 8)	6 7 (3 8-9 5)	6 7 (3 8-9 6)	15 2 (9 7-20 6)	19 6 (12 6-26 2)	4 0 (2 3-5 8)	4 0 (2 3-5 8)
AMR-B	2 6 (1 6-3 6)	1 6 (1 0-2 1)	3 7 (2 1-5 3)	3 4 (1 9-4 8)	9 9 (6 3-13 5)	12 7 (8 1-17 2)	1 6 (0 9-2 3)	1 6 (0 9-2 3)
AMR-D	4 8 (3 0-6 6)	3 7 (2 3-5 2)	5 4 (3 0-7 7)	5 6 (3 2-8 0)	13 3 (8 4-18 1)	17 7 (11 3-23 8)	2 7 (1 5-3 9)	2 7 (1 5-3 9)
EMR-B	15 0 (9 5-20 3)	0 4 (0 2-0 6)	16 2 (9 4-22 5)	3 1 (1 7-4 4)	22 6 (14 6-30 1)	13 2 (8 4-17 9)	13 3 (7 7-18 7)	13 8 (8 0-19 3)
EMR-D	17 8 (11 4-23 9)	0 0 (0 0-0 0)	21 1 (12 5-29 1)	2 9 (1 6-4 2)	25 2 (16 4-33 3)	13 0 (8 2-17 6)	16 6 (9 7-23 2)	18 9 (11 1-26 2)
EUR-A	9 8 (6 2-13 4)	6 7 (4 2-9 1)	9 5 (5 5-13 5)	7 7 (4 4-11 0)	17 9 (11 5-24 1)	20 3 (13 1-27 1)	7 0 (4 0-9 9)	7 0 (4 0-9 9)
EUR-B	10 4 (6 5-14 2)	5 2 (3 3-7 2)	10 0 (5 7-14 1)	6 6 (3 8-9 4)	18 5 (11 8-24 8)	18 8 (12 1-25 2)	7 4 (4 2-10 6)	7 4 (4 2-10 6)
EUR-C	5 8 (3 6-7 9)	3 3 (2 0-4 5)	5 9 (3 4-8 5)	5 3 (3 0-7 6)	14 2 (9 0-19 3)	17 5 (11 2-23 5)	3 3 (1 9-4 7)	3 3 (1 9-4 7)
SEAR-B	9 1 (5 7-12 4)	7 8 (4 9-10 7)	9 2 (5 3-13 0)	8 6 (4 9-12 1)	17 3 (11 1-23 2)	20 5 (13 2-27 3)	6 6 (3 8-9 4)	6 6 (3 8-9 4)
SEAR-D	1 3 (0 8-1 8)	0 0 (0 0-0 0)	3 3 (1 9-4 8)	1 8 (1 0-2 6)	10 2 (6 4-14 0)	9 7 (6 1-13 3)	0 6 (0 3-0 9)	0 6 (0 3-0 9)
WPR-A	9 5 (6 0-13 0)	7 2 (4 5-9 9)	9 3 (5 3-13 1)	7 8 (4 4-11 0)	17 1 (11 0-23 0)	19 9 (12 8-26 6)	6 9 (3 9-9 8)	6 7 (3 9-9 6)
WPR-B	15 1 (9 7-20 2)	13 4 (8 5-17 9)	19 8 (11 9-26 9)	18 0 (10 7-24 6)	22 7 (14 8-30 1)	26 1 (17 1-34 2)	11 5 (6 7-16 1)	16 1 (9 5-22 1)
World	7 9 (5 0-10 7)	3 9 (2 5-5 4)	9 0 (5 2-12 5)	5 8 (3 3-8 2)	15 7 (10 0-21 1)	16 1 (10 3-21 6)	5 9 (3 4-8 4)	6 5 (3 7-9 1)

Table 6 12 Attributable fractions of adult cardiopulmonary disease mortality (AF_{CPD}) associated with $PM_{2\ 5}$

WHO Subregion	AF_{CPD} associated with $PM_{2\ 5}$							
	Selection of C-R function		**Theoretical minimum**				**Maximum exposure threshold**	
	Scenario 2 Total Log-linear, Ref 5 8	Scenario 2 No Dust Log-linear, Ref 5 8	Scenario 3_Total Linear, Ref 2 1	Scenario 3_No Dust Linear, Ref 0 8	Scenario 4 Total Log-linear, Ref 2 1	Scenario 4 No Dust Log-linear, Ref 0 8	Scenario 5 Linear, Ref 5 8, Max 30	Scenario 6 Linear, Ref 5 8, Max Hybrid
AFR-D	1 3 (0 6-1 7)	0 0 (0 0-0 0)	2 7 (1 7-3 6)	0 5 (0 3-0 7)	7 3 (4 9-9 6)	3 6 (2 4-4 8)	1 2 (0 7-1 6)	1 2 (0 7-1 6)
AFR-E	2 2 (1 5-3 0)	0 0 (0 0-0 0)	5 3 (3 3-7 3)	5 7 (3 5-7 8)	15 6 (10 5-20 3)	21 8 (14 8-28 1)	1 0 (0 6-1 4)	1 0 (0 6-1 4)
AMR-A	10 5 (7 0-13 8)	8 7 (5 8-11 5)	10 5 (6 6-14 2)	10 6 (6 6-14 3)	22 8 (15 6-29 4)	28 9 (20 0-36 8)	6 4 (4 0-8 7)	6 4 (4 0-8 7)
AMR-B	3 7 (2 5-4 9)	2 0 (1 4-2 7)	5 6 (3 5-7 7)	5 0 (3 1-6 8)	14 8 (10 0-19 2)	18 6 (12 7-24 0)	2 3 (1 4-3 1)	2 3 (1 4-3 1
AMR-D	7 3 (4 9-9 7)	5 8 (3 9-7 7)	8 4 (5 3-11 5)	8 8 (5 5-12 0)	20 1 (13 7-26 0)	26 4 (18 2-33 7)	4 3 (2 7-5 9)	4 3 (2 7-5 9)
EMR-B	22 5 (15 4-29 0)	0 4 (0 3-0 5)	24 7 (16 1-32 5)	4 6 (2 9-6 4)	33 2 (23 2-41 9)	19 5 (13 2-25 2)	20 2 (13 0-26 9)	21 3 (13 8-28 2)
EMR-D	26 5 (18 2-33 9)	0 0 (0 0-0 0)	31 7 (20 9-41 1)	4 6 (2 9-6 3)	36 6 (25 8-45 8)	19 6 (13 3-25 4)	25 3 (16 4-33 3)	28 6 (18 7-37 3)
EUR-A	15 0 (10 1-19 6)	10 3 (6 9-13 6)	14 9 (9 5-20 0)	12 2 (7 7-16 5)	26 7 (18 4-34 2)	30 0 (20 9-38 1)	11 0 (6 9-14 9)	11 0 (6 9-14 9)
EUR-B	15 8 (10 6-20 7)	7 7 (5 1-10 2)	15 5 (9 8-20 8)	10 2 (6 4-13 8)	27 4 (18 9-35 0)	27 6 (19 1-35 2)	11 6 (7 3-15 7)	11 6 (7 3-15 7)
EUR-C	8 9 (5 9-11 8)	5 1 (3 4-6 8)	9 4 (5 9-12 8)	8 4 (5 3-11 5)	21 5 (14 6-27 7)	26 1 (17 9-33 4)	5 3 (3 3-7 2)	5 3 (3 3-7 2)
SEAR-B	12 2 (8 2-16 0)	10 3 (6 9-13 4)	13 1 (8 3-17 6)	11 9 (7 6-16 1)	24 3 (16 7-31 2)	28 3 (19 7-35 9)	9 1 (5 8-12 3)	9 1 (5 8-12 3)
SEAR-D	2 1 (1 4-2 8)	0 0 (0 0-0 0)	5 3 (3 3-7 2)	2 8 (1 8-3 9)	15 6 (10 5-20 4)	14 8 (9 9-19 4)	1 0 (0 6-1 3)	1 0 (0 6-1 3)
WPR-A	14 5 (9 7-18 9)	11 1 (7 4-14 6)	14 4 (9 1-19 3)	12 1 (7 7-16 4)	25 5 (17 6-32 5)	29 3 (20 4-37 1)	10 8 (6 8-14 6)	10 8 (6 8-14 6)
WPR-B	23 5 (16 3-30 0)	21 1 (14 6-26 9)	31 5 (21 3-40 0)	28 9 (19 3-36 9)	34 1 (24 0-42 6)	38 5 (27 4-47 7)	18 4 (11 9-24 3)	25 1 (16 7-32 4)
World	11 9 (8 0-15 4)	5 9 (4 0-7 7)	13 8 (8 9-18 3)	9 0 (5 8-12 1)	23 2 (16 0-29 7)	23 8 (16 4-30 4)	9 1 (5 8-12 2)	9 9 (6 4-13 2)

Table 6.13 Attributable fractions of adult lung cancer mortality (AF_{LC}) associated with $PM_{2 5}$ (95% CIs)

WHO Subregion	AF_{LC} associated with $PM_{2 5}$							
	Selection of C-R function		**Theoretical minimum**				**Maximum exposure threshold**	
	Scenario 2_{Total} Log-linear, Ref 5 8	Scenario $2_{No Dust}$ Log-linear, Ref 5 8	Scenario 3_{Total} Linear, Ref 2 1	Scenario $3_{No Dust}$ Linear, Ref 0 8	Scenario 4_{Total} Log-linear, Ref 2 1	Scenario $4_{No Dust}$ Log-linear, Ref 0 8	Scenario 5 Linear, Ref 5 8, Max 30	Scenario 6 Linear, Ref 5 8, Max Hybrid
AFR-D	0 9 (0 5-1 2)	0 0 (0 0-0 0)	2 1 (0 9-3 3)	0 4 (0 2-0 7)	6 6 (3 5-9 5)	3 3 (1 7-4 9)	0 8 (0 3-1 1)	0 8 (0 3-1 1)
AFR-E	2 4 (1 3-3 6)	0 0 (0 0-0 0)	5 8 (2 4-9 0)	6 2 (2 6-9 6)	17 2 (9 2-24 5)	24 0 (13 1-33 6)	1 1 (0 5-1 8)	1 1 (0 5-1 8)
AMR-A	11 7 (6 1-16 9)	9 7 (5 1-14 2)	11 5 (5 0-17 5)	11 6 (5 0-17 7)	25 2 (13 8-35 1)	31 8 (17 8-43 5)	7 0 (3 0-10 9)	7 0 (3 0-10 9)
AMR-B	4 1 (2 2-6 0)	2 1 (1 1-3 0)	6 2 (2 7-9 6)	5 4 (2 3-8 3)	16 5 (8 9-23 4)	20 3 (11 0-28 5)	2 5 (1 1-3 8)	2 5 (1 1-3 8)
AMR-D	9 0 (4 7-13 1)	7 5 (3 9-11 0)	9 8 (4 2-15 0)	10 3 (4 5-15 8)	22 9 (12 5-32 1)	29 9 (16 7-41 1)	5 3 (2 2-8 2)	5 3 (2 2-8 2)
EMR-B	24 8 (13 6-34 7)	0 2 (0 1-0 3)	26 9 (12 3-38 9)	4 8 (2 0-7 5)	36 3 (20 6-49 0)	21 0 (11 3-29 6)	21 8 (9 8-32 2)	23 2 (10 5-34 0)
EMR-D	29 1 (16 1-40 2)	0 0 (0 0-0 0)	34 3 (16 1-48 5)	5 0 (2 1-7 9)	40 0 (23 0-53 3)	21 6 (11 7-30 5)	27 5 (12 6-39 9)	31 0 (14 3-44 4)
EUR-A	16 8 (9 0-24 0)	11 7 (6 2-16 9)	16 4 (7 2-24 7)	13 5 (5 9-20 5)	29 6 (16 4-40 7)	33 2 (18 7-45 1)	12 2 (5 3-18 6)	12 2 (5 3-18 6)
EUR-B	17 3 (9 3-24 7)	11 4 (6 0-16 5)	16 6 (7 3-25 0)	13 2 (5 7-20 0)	30 0 (16 7-41 2)	32 9 (18 5-44 9)	12 4 (5 4-18 9)	12 4 (5 4-18 9)
EUR-C	10 1 (5 3-14 7)	6 0 (3 1-8 8)	10 5 (4 5-16 1)	9 4 (4 0-14 5)	23 9 (13 0-33 4)	28 9 (16 0-39 8)	6 0 (2 6-9 3)	6 0 (2 6-9 3)
SEAR-B	18 1 (9 7-25 7)	16 1 (8 6-23 0)	17 8 (7 8-26 6)	16 9 (7 5-25 4)	30 6 (17 1-42 0)	36 3 (20 6-48 9)	13 6 (5 9-20 6)	13 6 (5 9-20 6)
SEAR-D	2 3 (1 2-3 4)	0 0 (0 0-0 0)	5 8 (2 5-9 0)	3 1 (1 3-4 9)	17 3 (9 2-24 7)	16 4 (8 8-23 5)	1 1 (0 4-1 7)	1 1 (0 4-1 7)
WPR-A	16 2 (8 7-23 0)	12 4 (6 6-17 9)	15 8 (7 0-23 8)	13 4 (5 8-20 3)	28 2 (15 7-38 8)	32 3 (18 2-43 9)	11 9 (5 2-18 1)	11 9 (5 2-18 1)
WPR-B	28 4 (15 9-38 9)	26 0 (14 5-35 8)	36 5 (17 8-50 0)	33 5 (16 1-46 5)	39 3 (22 7-52 3)	44 1 (25 9-57 8)	22 5 (10 2-33 0)	30 2 (14 3-42 5)
World	13 7 (7 4-19 3)	7 4 (4 0-10 5)	15 4 (7 0-22 6)	10 5 (4 7-15 7)	26 0 (14 4-35 7)	26 9 (15 0-36 8)	10 4 (4 6-15 6)	11 3 (5 1-16 7)

Table 6 14 Attributable fractions of adult ischemic heart disease mortality (AF_{IHD}) associated with $PM_{2 5}$

WHO Subregion	**AF_{IHD} associated with $PM_{2 5}$**							
	Selection of C-R function		**Theoretical minimum**				**Maximum exposure threshold**	
	Scenario 2_{Total} Log-linear, Ref 5 8	Scenario $2_{No Dust}$ Log-linear, Ref 5 8	Scenario $3_{\_Total}$ Linear, Ref 2 1	Scenario $3_{\_No Dust}$ Linear, Ref 0 8	Scenario $4_{\_Total}$ Log-linear, Ref 2 1	Scenario $4_{\_No Dust}$ Log-linear, Ref 0 8	Scenario 5 Linear, Ref 5 8, Max 30	Scenario 6 Linear, Ref 5 8, Max Hybrid
AFR-D	0 5 (0 3-0 5)	0 0 (0 0-0 0)	3 2 (2 1-4 3)	0 9 (0 6-1 3)	11 8 (8 3-15 0)	7 0 (4 9-9 0)	0 4 (0 3-0 5)	0 4 (0 3-0 5)
AFR-E	4 6 (3 2-6 0)	0 0 (0 0-0 0)	10 8 (7 1-14 3)	11 5 (7 6-15 3)	29 8 (21 6-36 9)	40 2 (29 7-48 8)	2 2 (1 4-2 9)	2 2 (1 4-2 9)
AMR-A	20 6 (14 7-25 9)	17 3 (12 3-21 9)	20 7 (13 9-26 9)	20 9 (14 0-27 1)	41 8 (31 0-50 5)	51 0 (38 6-60 4)	12 9 (8 5-17 0)	12 9 (8 5-17 0)
AMR-B	9 3 (6 6-11 7)	5 2 (3 7-6 5)	12 7 (8 5-16 6)	11 2 (7 5-14 7)	29 9 (21 9-36 7)	36 1 (26 7-43 8)	5 9 (3 9-7 7)	5 9 (3 9-7 7)
AMR-D	13 2 (9 3-16 6)	10 2 (7 2-13 0)	16 0 (10 7-20 9)	16 5 (11 0-21 6)	36 3 (26 6-44 3)	45 7 (34 3-54 7)	7 8 (5 1-10 3)	7 8 (5 1-10 3)
EMR-B	43 4 (32 3-52 2)	1 9 (1 3-2 5)	48 2 (34 8-58 7)	10 9 (7 2-14 5)	58 4 (45 2-68 0)	38 8 (28 6-47 1)	40 5 (28 5-50 4)	43 1 (30 7-53 1)
EMR-D	47 4 (35 6-56 7)	0 3 (0 2-0 4)	55 0 (40 3-66 1)	9 6 (6 3-12 8)	61 4 (47 9-71 0)	36 7 (26 9-44 9)	45 7 (32 6-56 2)	50 6 (36 6-61 5)
EUR-A	28 5 (20 6-35 2)	20 7 (14 8-25 8)	28 5 (19 5-36 4)	24 1 (16 4-31 0)	47 5 (35 8-56 7)	52 7 (40 3-62 1)	21 5 (14 5-27 8)	21 5 (14 5-27 8)
EUR-B	30 4 (22 0-37 6)	13 3 (8 9-16 7)	29 9 (20 6-38 2)	18 7 (12 6-24 2)	48 9 (36 9-58 3)	47 2 (35 6-56 2)	23 1 (15 6-29 8)	23 1 (15 6-29 8)
EUR-C	18 2 (12 9-23 0)	11 1 (7 8-14 2)	19 1 (12 8-24 9)	17 2 (11 5-22 5)	40 0 (29 6-48 5)	47 2 (35 5-56 4)	11 1 (7 4-14 7)	11 1 (7 4-14 7)
SEAR-B	23 0 (16 6-28 4)	19 3 (13 9-23 9)	24 9 (17 0-31 8)	22 7 (15 5-29 1)	43 5 (32 6-52 1)	49 0 (37 4-57 8)	17 5 (11 9-22 6)	17 5 (11 9-22 6)
SEAR-D	4 3 (3 0-5 5)	0 0 (0 0-0 0)	10 7 (7 1-14 2)	5 9 (3 8-7 9)	29 8 (21 5-36 8)	28 4 (20 4-35 2)	2 0 (1 3-2 7)	2 0 (1 3-2 7)
WPR-A	22 6 (16 4-27 9)	17 9 (12 8-22 3)	23 3 (16 0-29 8)	20 1 (13 6-25 9)	39 9 (29 9-47 8)	45 2 (34 4-53 5)	17 4 (11 8-22 5)	17 4 (11 8-22 5)
WPR-B	39 4 (29 7-46 9)	35 0 (26 4-41 8)	48 8 (36 9-57 3)	45 6 (34 0-54 1)	55 4 (43 1-64 4)	61 3 (48 4-70 2)	31 8 (22 4-39 5)	40 3 (29 7-48 3)
World	21 8 (16 0-26 7)	11 7 (8 4-14 5)	25 1 (17 7-31 5)	16 8 (11 6-21 6)	41 0 (30 8-49 1)	41 9 (31 6-50 0)	17 1 (11 8-21 8)	18 3 (12 8-23 0)

6.3.2.1 Concentration-response function

Figures 6.9 to 6.12 show the fractions of mortality attributable to $PM_{2.5}$ under the base case compared to the equivalent log-linear scenario for the total and anthropogenic components of $PM_{2.5}$, for all four causes of mortality. The log-linear models, compared to their linear counterparts produced higher world attributable fraction estimates across all scenarios for all causes of mortality. Additionally, the log-linear scenarios, compared to their linear equivalents, produced higher attributable fraction estimates for all four causes of mortality, and across all subregions except for subregions EMR-D and WPR-B. The log-linear model for $PM_{2.5\_Total}$ where the reference value is set to 5.8μg/m^3 produced lower AF estimates compared to the linear model for EMR-D (scenario $2_{\_Total}$ versus $1_{\_Total}$); however, the linear model for $PM_{2.5\_Total}$ where the reference value was set to 2.1μg/m^3 produced smaller AF estimates compared to the log-linear model (scenario $4_{\_Total}$ versus $3_{\_Total}$) as did the $PM_{2.5\_No\ Dust}$ linear models (scenarios $2_{\_No\ Dust}$ versus $1_{\_No\ Dust}$; $4_{\_No\ Dust}$ versus $3_{\_No\ Dust}$) for this subregion. When the reference value was set to 5.8μg/m^3, the log-linear models produced lower estimates for WPR-B for the total and anthropogenic components of $PM_{2.5}$ (scenarios 2 versus 1).

The African subregions, AFR-D and AFR-E, were most sensitive the choice of the concentration-response function, and were associated with the greatest percent changes for the four linear versus log-linear comparisons.

The differences in the attributable fraction estimates associated with $PM_{2.5\_Total}$ versus $PM_{2.5\_No\ Dust}$ were greater under the log-linear concentration-response functions (scenario 2) compared to the base case.

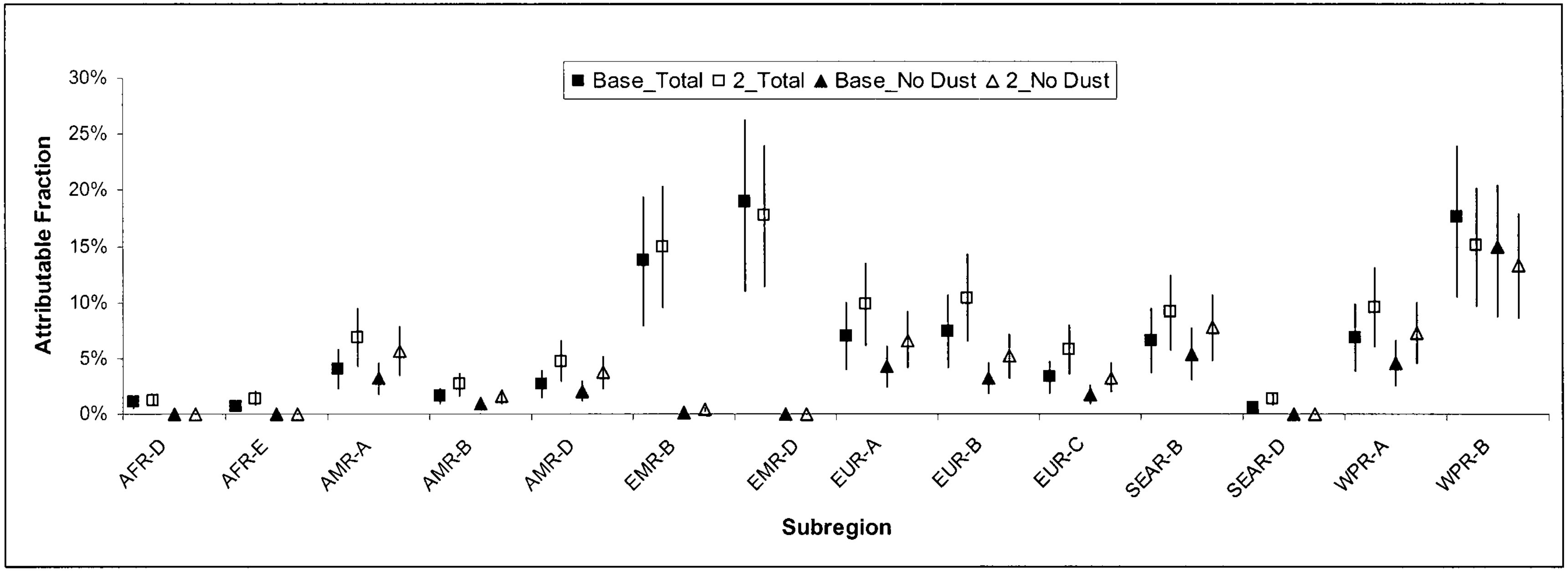

Figure 6.9 Attributable fractions of adult all cause mortality under the base case compared to the equivalent log-linear scenario (scenario 2) for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$

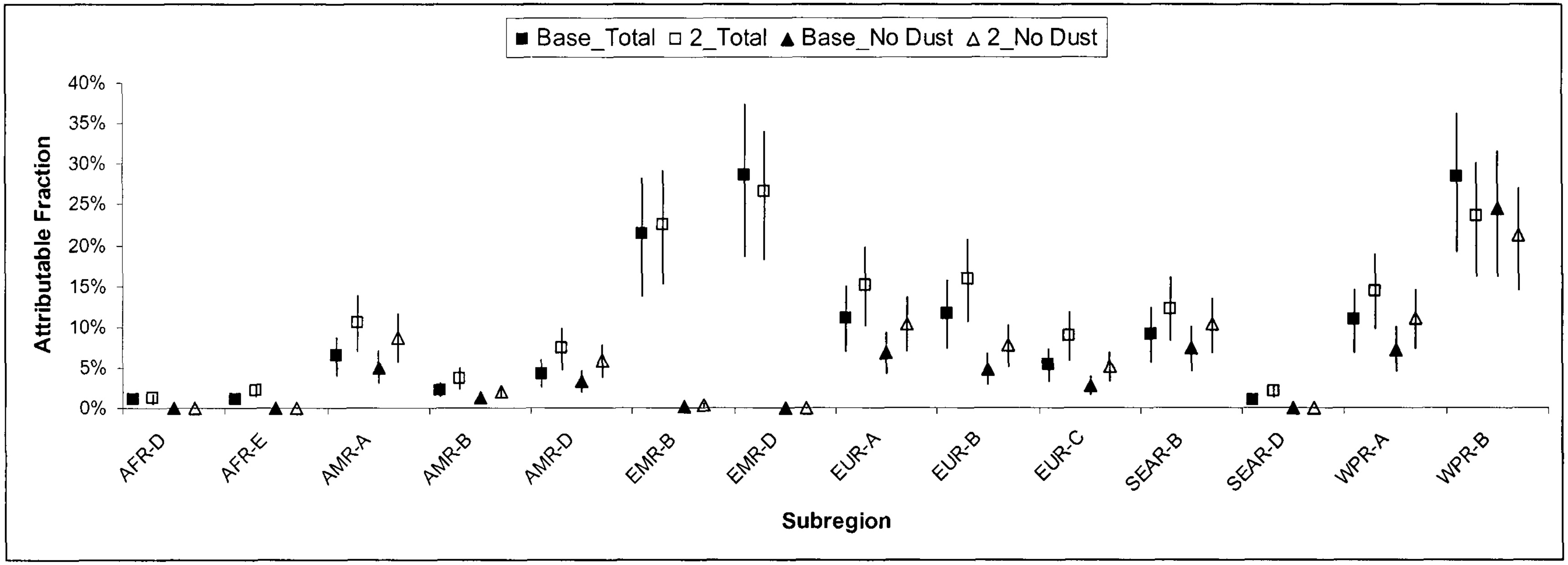

Figure 6.10 Attributable fractions of adult cardiopulmonary disease mortality under the base case compared to the equivalent log-linear scenario (scenario 2) for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$

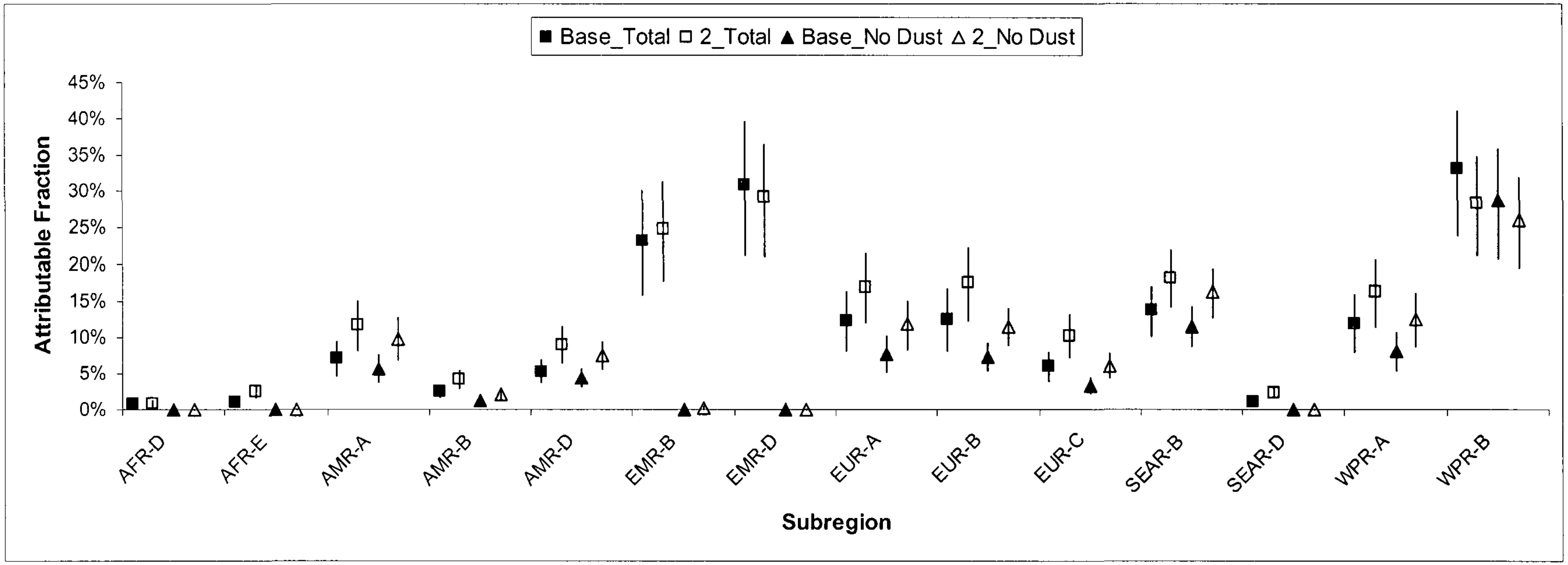

Figure 6.11 Attributable fractions of adult lung cancer mortality under the base case compared to the equivalent log-linear scenario (scenario 2) for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$

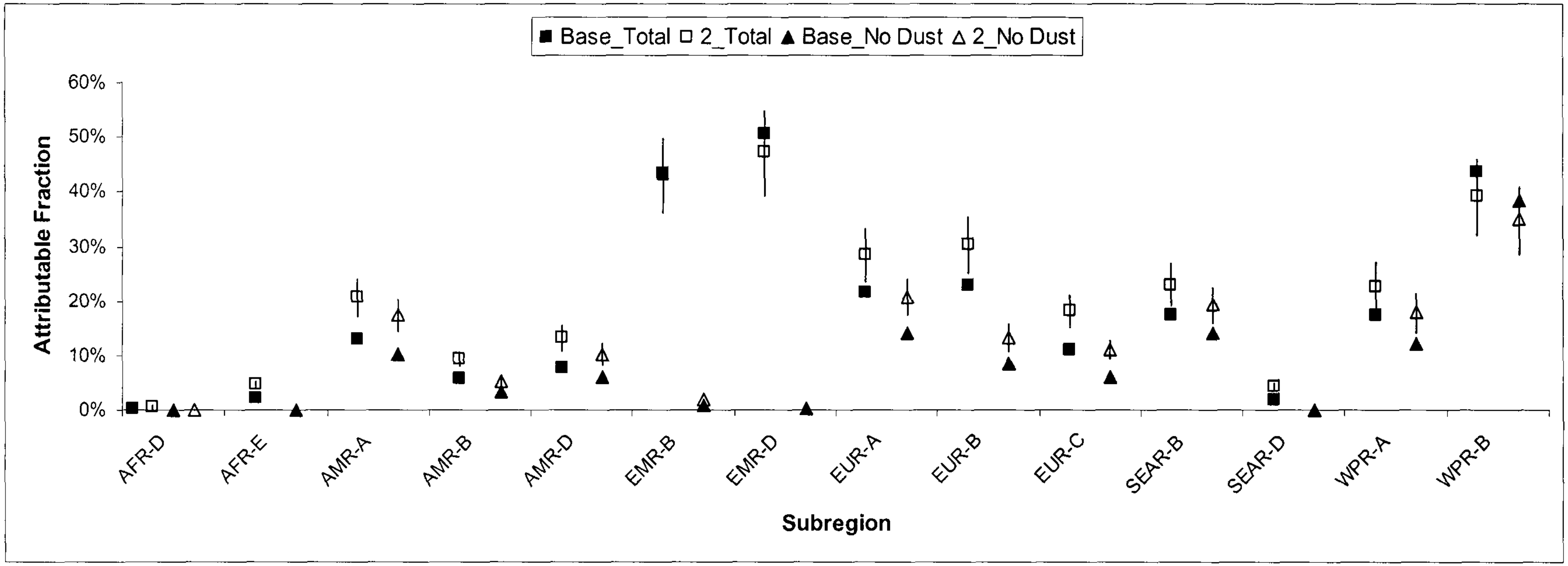

Figure 6.12 Attributable fractions of adult ischemic heart disease mortality under the base case compared to the equivalent log-linear scenario (scenario 2) for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$

6.3.2.2 Theoretical- minimum concentration

Decreasing the theoretical-minimum from 5.8μg/m^3 to 2.1μg/m^3 for $PM_{2\ 5\_Total}$, and from 5.8μg/m^3 to 0.8μg/m^3 for $PM_{2\ 5\_No\ Dust}$ resulted in higher attributable fraction estimates. Figures 6.13 to 6.16 show the fractions of all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortality attributable to $PM_{2\ 5}$ under the base case compared to the scenario (scenario 3) where the reference value was decreased to the lowest concentrations observed for the total and anthropogenic component of $PM_{2\ 5}$.

For the linear concentration-response functions, the decreases in attributable fractions that arose when the theoretical-minimum was lowered were comparable across most subregions, for all four air pollution causes of mortality. One notable exception was AFR-D, where the decreases were smaller compared to other subregions. The log-linear concentration-response functions amplified the aforementioned decreases, and enhanced variations by subregion.

The decreases in attributable fractions were larger for $PM_{2\ 5\_No\ Dust}$ as the lowest observed concentration in the current study was lower than that observed for the total component of $PM_{2\ 5}$, 0.8μg/m^3 versus 2.1μg/m^3. The larger decreases associated with the anthropogenic component of $PM_{2\ 5}$ was more apparent for the log-linear functions.

Unlike the base case scenario, when the reference value was set to 2.1μg/m^3 and 0.8μg/m^3 for $PM_{2\ 5\_Total}$ and $PM_{2\ 5\_No\ Dust}$ respectively, the scenarios involving the anthropogenic component of $PM_{2\ 5}$ were not always lower than those for the total component. There was a slight increase in the attributable fraction of mortality associated with $PM_{2\ 5}$ when the dust component of $PM_{2\ 5}$ was removed for subregions AFR-E and AMR-D under the linear function scenarios (scenarios 3 versus the base case). Similarly, attributable fractions of mortality increased for subregions AFR-E, AMR-A/D, EUR-A/C, SEAR-B, and WPR-A/B when the dust component of $PM_{2\ 5}$ was removed under the log-linear concentration-response function. Decreases can be attributed to the lower reference values for the $PM_{2\ 5\_No\ Dust}$ scenarios compared to those for the total component of $PM_{2\ 5}$, 0.8μg/m^3 versus 2.1μg/m^3 respectively.

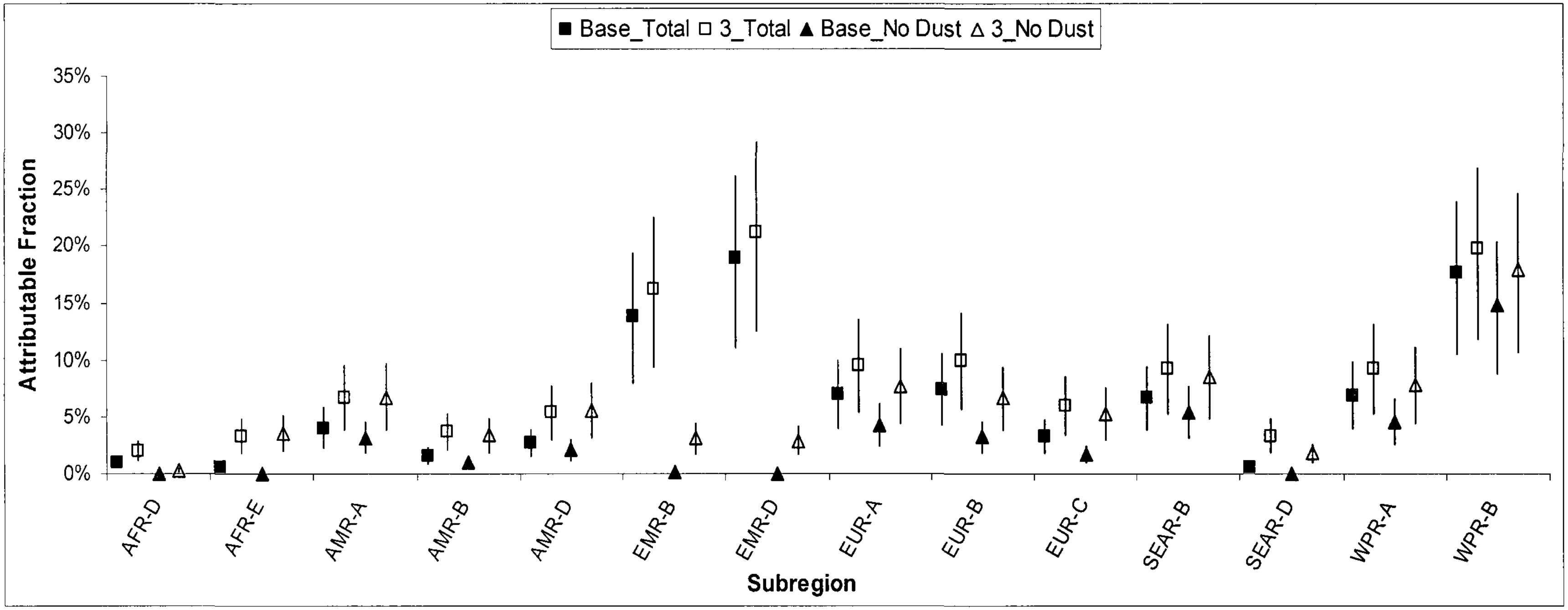

Figure 6.13 Attributable fractions of adult all cause mortality under the base case compared to the equivalent scenario (scenario 3) where the reference values were decreased to the lowest observed concentrations for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$

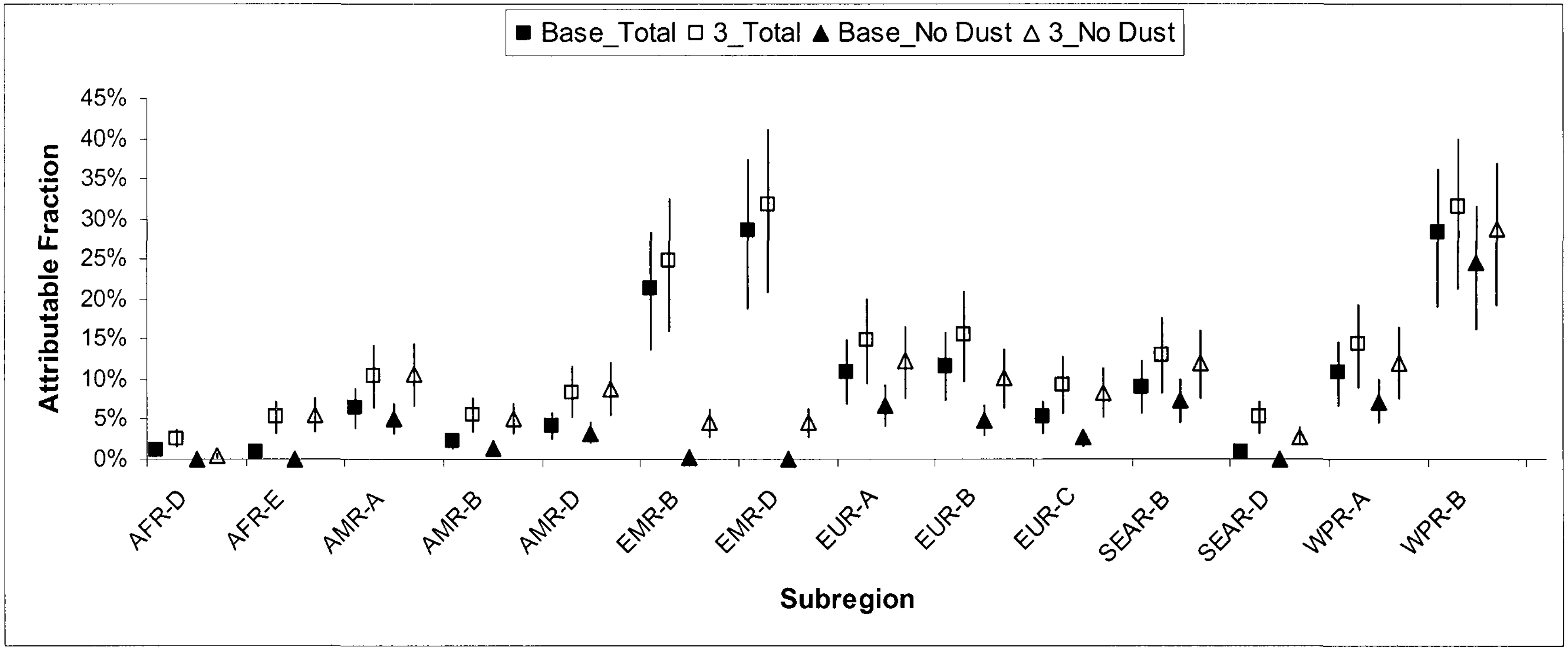

Figure 6.14 Attributable fractions of adult cardiopulmonary disease mortality under the base case compared to the equivalent scenario (scenario 3) where the reference values were decreased to the lowest observed concentrations for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$

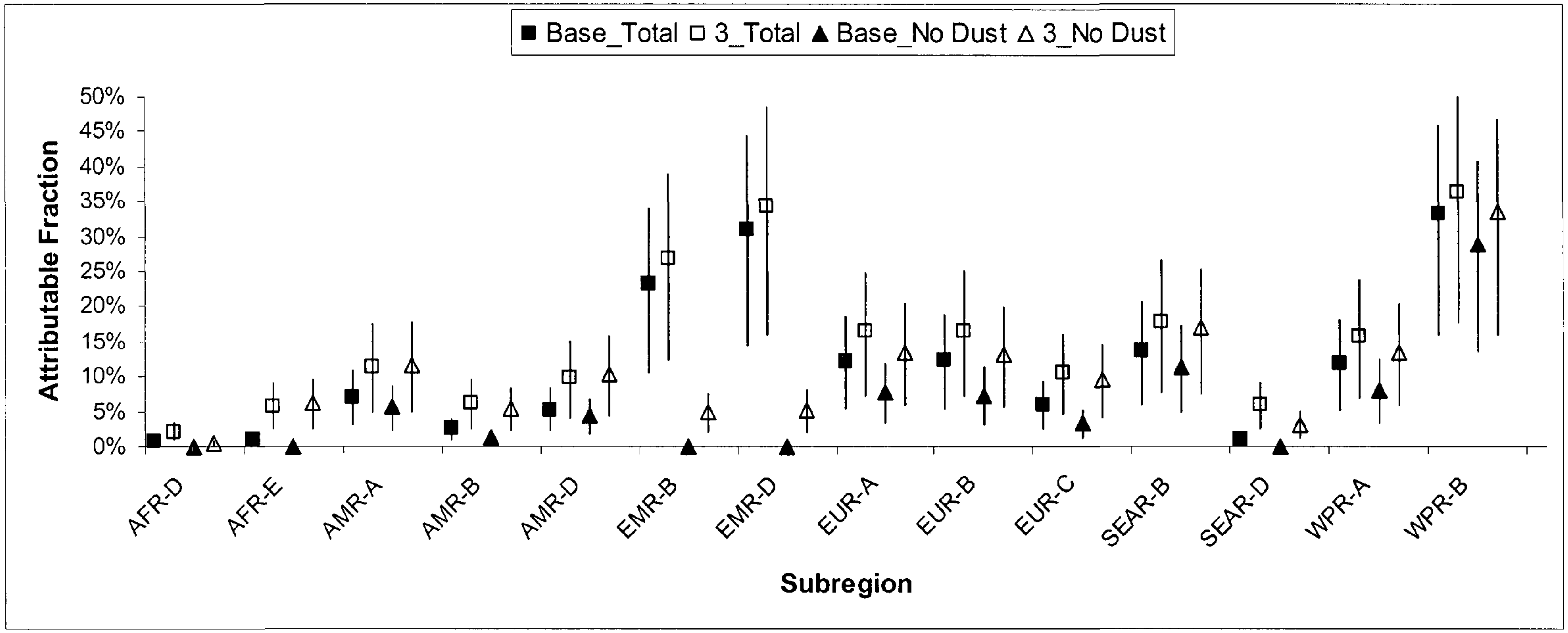

Figure 6.15 Attributable fractions of adult lung cancer mortality under the base case compared to the equivalent scenario (scenario 3) where the reference values were decreased to the lowest observed concentrations for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$

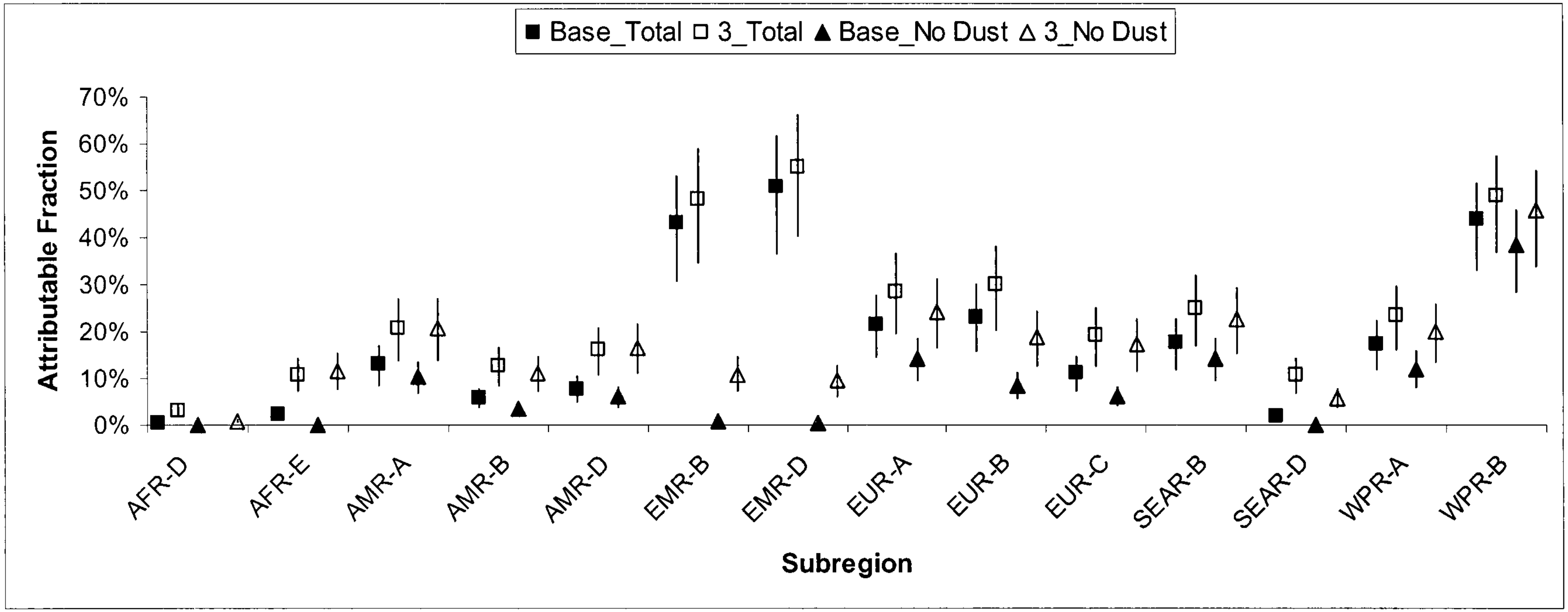

Figure 6.16 Attributable fractions of adult ischemic heart disease mortality under the base case compared to the equivalent scenario (scenario 3) where the reference values were decreased to the lowest observed concentrations for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$

6.3.2.3 Maximum exposure threshold

Figures 6.17 to 6.20 present the base case scenario compared to scenarios were risk was maximized at 30μg/m^3 as well as at the intersection between linear and log-linear models.

Maximizing the risk at 30μg/m^3 decreased attributable fraction estimates as compared with the base case for subregions EMR-B/D and WPR-B, for all four air pollution causes of mortality; estimates for all other subregions were the same under the base case and scenario 5. Maximizing the risk at the intersection point of the linear and log-linear models decreased the attributable fractions as compared to the base case for subregion WPR-B for all four air pollution causes of mortality. Since no other subregions had countries with concentrations higher than this intersection point, the estimates from scenario 6 were the same as the base case for all other subregions.

Overall, maximizing risk did not have a large effect on the base case estimates since only three subregions had country-level concentrations above 30μg/m^3 (EMR-B/D and WPR-D), and of these, only one (WPR-B) had country-level concentrations higher than the concentration at which linear and log-linear models intersect.

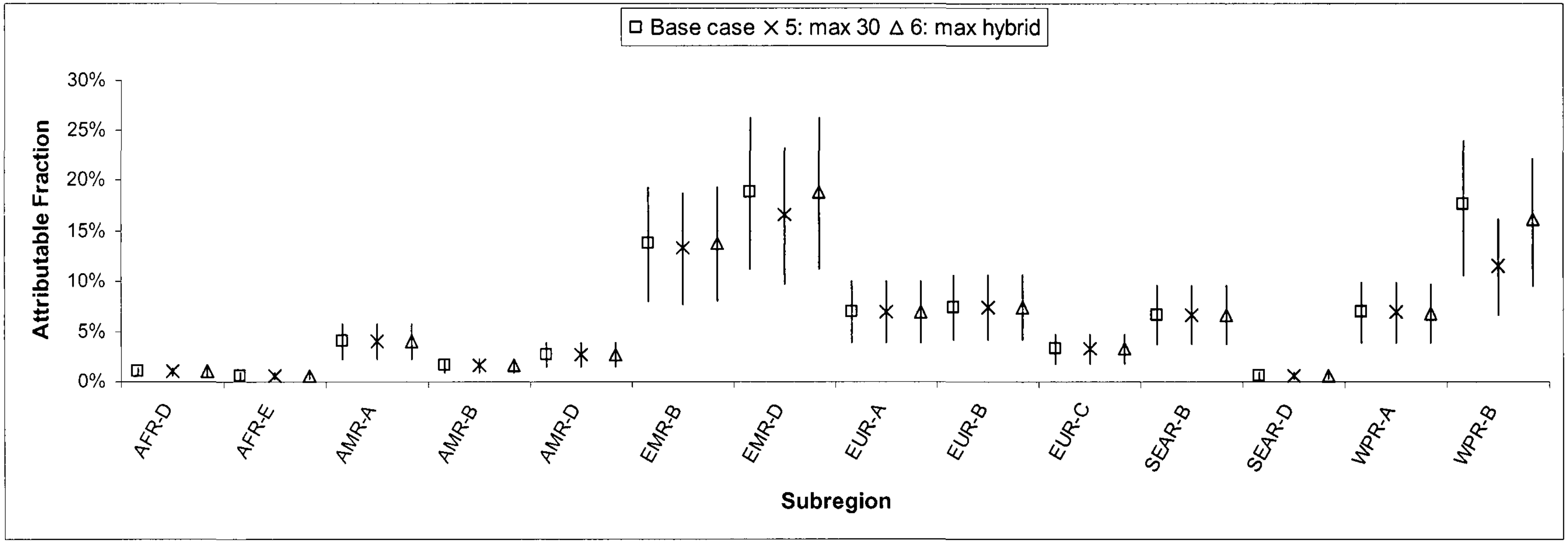

Figure 6.17 Attributable fractions of adult all cause mortality under scenarios where risk is maximized compared to the base case

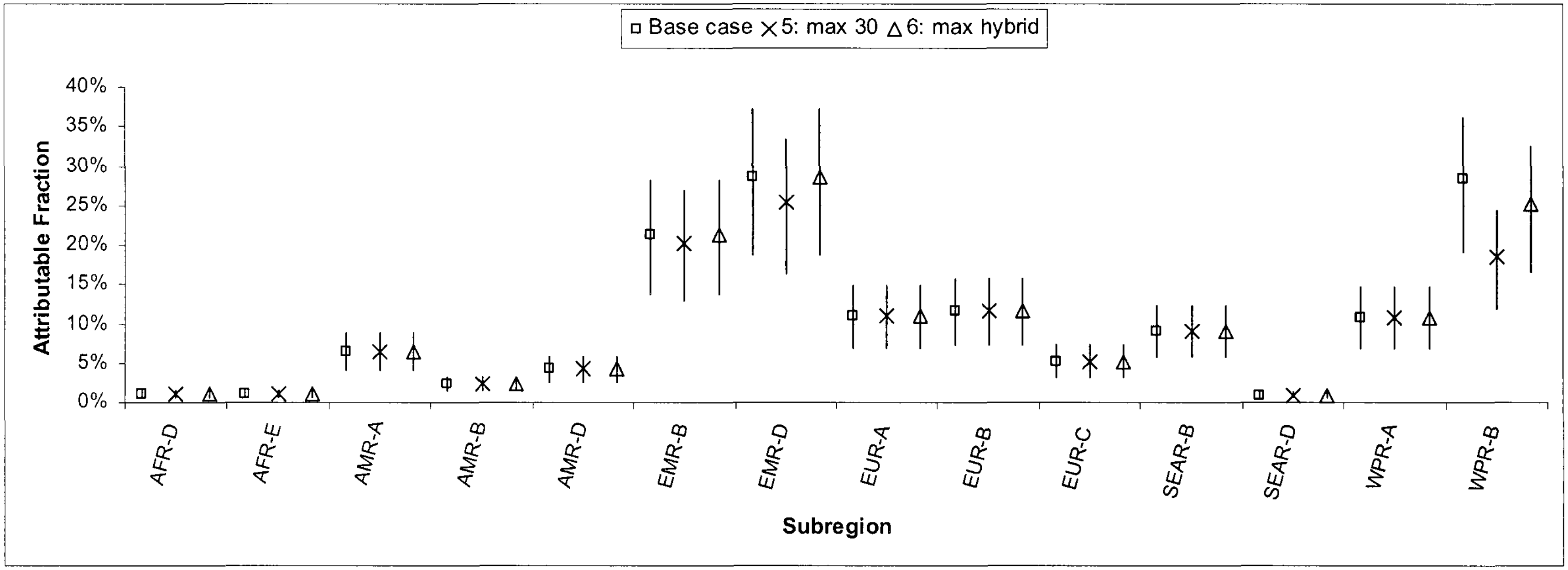

Figure 6.18 Attributable fractions of adult cardiopulmonary disease mortality under scenarios where risk is maximized compared to the base case

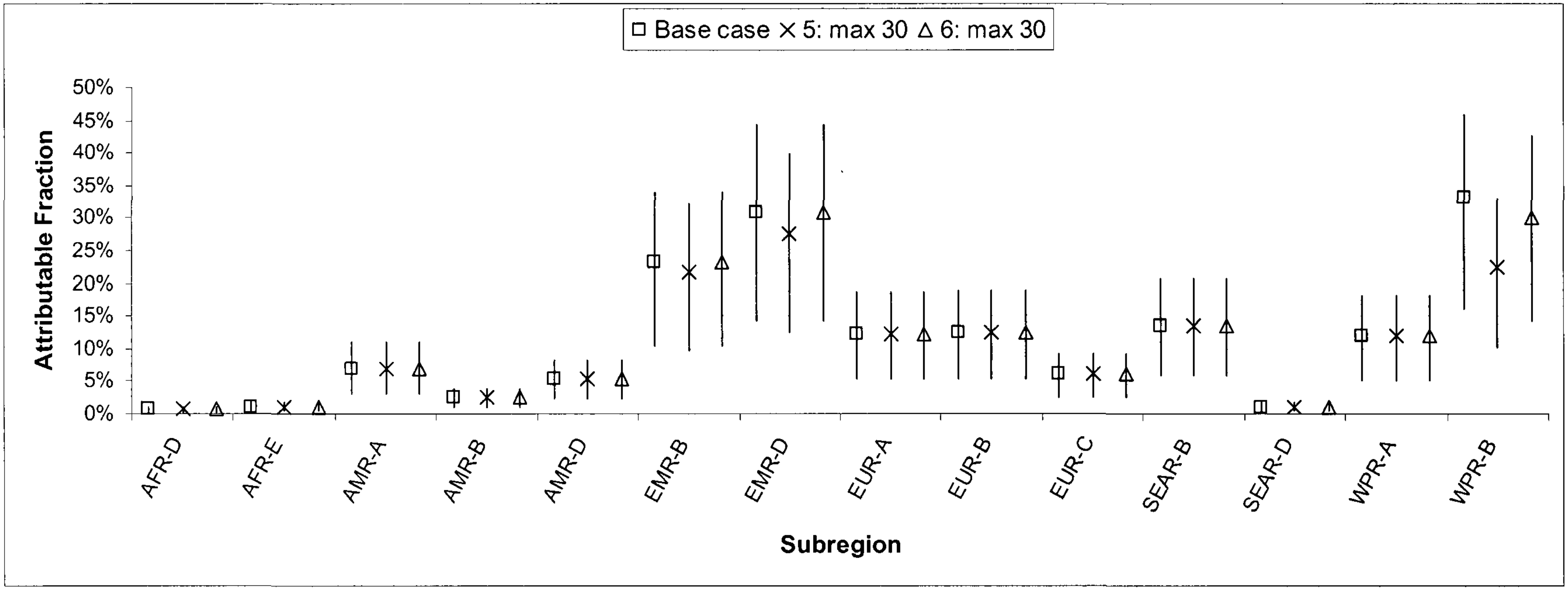

Figure 6.19 Attributable fractions of adult lung cancer mortality under scenarios where risk is maximized compared to the base case

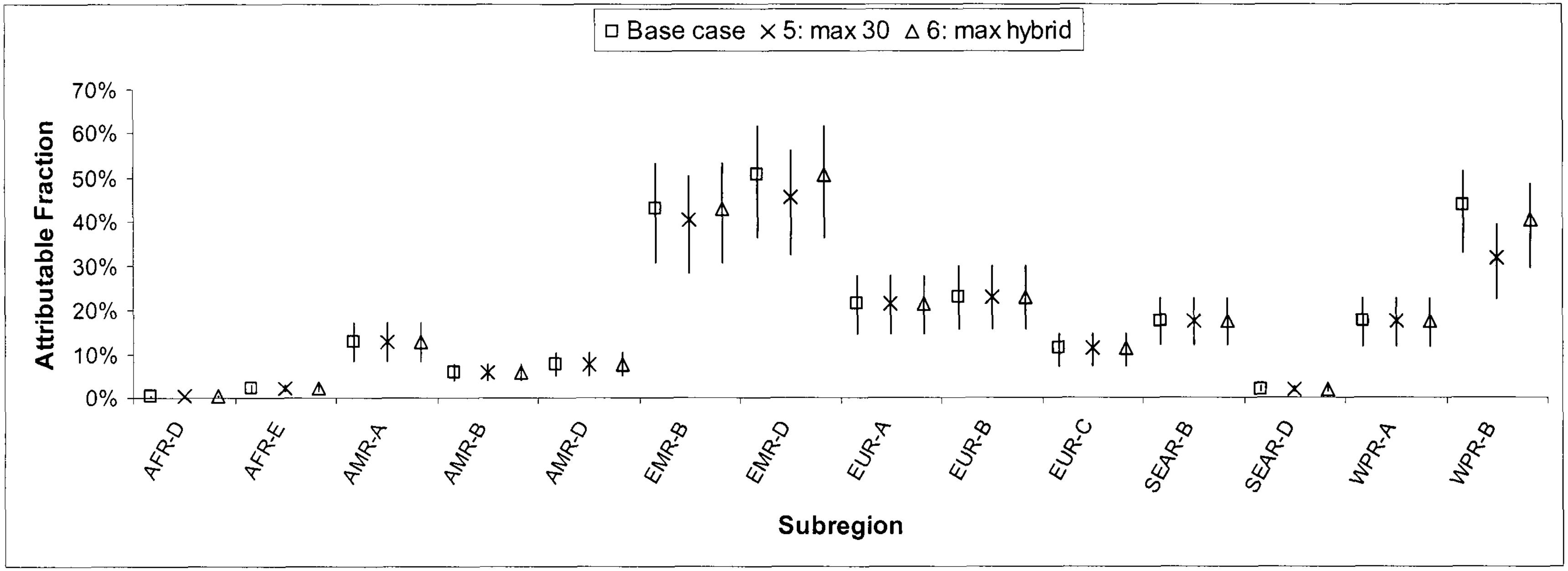

Figure 6.20 Attributable fractions of adult ischemic heart disease mortality under scenarios where risk is maximized compared to the base case

6.3.3 Number of Subregional and Global Deaths Attributable to $PM_{2.5}$

6.3.3.1 Base case scenario

Although required for the calculation of subregional and global attributable fraction estimates, the country-level mortality estimates from the WHO mortality database only represent 132 countries, and as a result, the 2004 WHO GBD update which is based on 192 countries was used to calculate the expected numbers of global deaths attributable to $PM_{2.5}$.

Table 6.15 provides the number of adult all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease deaths in 2004 which were attributable to $PM_{2.5}$ under the base case scenario. Subregional mortality from all causes, lung cancer, cardiopulmonary disease, and ischemic heart disease was obtained from the most recent update to the Global Burden of Disease (GBD) project,(90)(3) which provided 2004 estimates of mortality.

Under the base case scenario, over 3 million adult all cause, 2.1 million cardiopulmonary disease, 1.3 million ischemic heart disease, and 152,400 lung cancer deaths in 2004 can be attributed to the total component of $PM_{2.5}$. Attributable mortality decreased with removal of the dust component of $PM_{2.5}$ with 1.4 million all cause, 926,000 cardiopulmonary disease, 588,000 ischemic heart disease, and 73,500 lung cancer deaths in 2004 being attributable to the anthropogenic component of $PM_{2.5}$.

Table 6.15 Attributable number of 2004 adult all cause mortality, cardiopulmonary disease, lung cancer, and ischemic heart disease deaths associated with $PM_{2.5}$ under the base case

WHO Subregion	Number of Deaths Attributable to $PM_{2.5}$ in 2004							
	All Cause (000s)		Cardiopulmonary Disease (000s)		Lung cancer (00s)		Ischemic Heart Disease (000s)	
	$PM_{2.5\_Total}$	$PM_{2.5\_No\ Dust}$	$PM_{2.5\_Total}$	$PM_{2.5\_No\ Dust}$	$PM_{2.5\_Total}$	$PM_{2.5\_No\ Dust}$	$PM_{2.5\_Total}$	$PM_{2.5\_No\ Dust}$
AFR-D	25 (14-35)	0 (0-0)	9 (6-12)	0 (0-0)	1 (0-1)	0 (0-0)	1 (0-1)	0 (0-0)
AFR-E	23 (13-33)	0 (0-0)	8 (5-11)	0 (0-0)	2 (1-2)	0 (0-0)	4 (2-5)	0 (0-0)
AMR-A	110 (62-158)	87 (49-125)	69 (43-95)	56 (37-75)	130 (56-202)	103 (44-161)	71 (47-93)	56 (37-75)
AMR-B	41 (23-59)	25 (14-36)	23 (14-31)	12 (8-16)	13 (6-21)	7 (3-11)	20 (14-27)	12 (8-16)
AMR-D	11 (6-16)	9 (5-12)	5 (3-7)	2 (1-2)	2 (1-4)	2 (1-3)	2 (2-3)	2 (1-2)
EMR-B	83 (48-116)	1 (1-2)	61 (40-81)	1 (1-2)	17 (8-25)	0 (0-0)	62 (45-77)	1 (1-2)
EMR-D	426 (250-590)	0 (0-0)	272 (178-355)	1 (1-1)	77 (36-111)	0 (0-0)	219 (158-266)	1 (1-1)
EUR-A	275 (157-392)	168 (95-241)	165 (104-224)	93 (63-122)	263 (114-400)	165 (71-253)	142 (96-183)	93 (63-122)
EUR-B	128 (73-182)	55 (31-80)	111 (70-150)	39 (26-51)	86 (37-132)	51 (22-78)	104 (70-134)	39 (26-51)
EUR-C	117 (66-169)	62 (35-89)	109 (68-150)	74 (48-98)	52 (22-80)	28 (12-44)	132 (88-175)	74 (48-98)
SEAR-B	156 (89-222)	127 (72-181)	78 (49-105)	39 (26-51)	70 (30-105)	58 (25-89)	48 (33-63)	39 (26-51)
SEAR-D	56 (31-81)	0 (0-0)	42 (26-58)	0 (0-0)	11 (5-17)	0 (0-0)	35 (22-47)	0 (0-0)
WPR-A	82 (47-117)	55 (31-78)	50 (32-68)	16 (11-21)	83 (36-127)	56 (24-87)	23 (15-29)	16 (11-21)
WPR-B	1780 (1063-2424)	1505 (891-2064)	1474 (993-1877)	345 (255-410)	1414 (683-1955)	1229 (583-1728)	393 (296-463)	345 (255-410)
World	3084 (1787-4325)	1357 (782-1914)	2077 (1341-2754)	588 (406-748)	1524 (688-2242)	735 (328-1096)	1331 (935-1668)	588 (406-748)

6.3.3.2 Sensitivity analyses

Tables 6.16 to 6.19 provide the number of adult all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease deaths in 2004 which were attributable to $PM_{2.5}$ under the 8 sensitivity scenarios.

Overall, the range of attributable deaths across all 10 scenarios was large for all four air pollution causes of mortality. All cause attributable mortality estimates ranged from 1.4 to 7.6 million deaths, cardiopulmonary disease attributable deaths ranged from 926,000 to 4.9 million, ischemic heart disease deaths ranged from 588,000 to 3 million, and lung cancer attributable deaths ranged from 73,500 to 355,000.

Subregion WPR-B produced the largest number of attributable deaths, contributing to approximately 50% of the global attributable number of deaths for all four causes of mortality under all sensitivity scenarios.

Table 6.16 Attributable number of 2004 adult all cause (AC) deaths due to $PM_{2.5}$ (95% CIs)

WHO Subregion	Number of adult AC deaths (000s) associated with $PM_{2.5}$							
	Selection of C-R function		**Theoretical minimum**				**Maximum exposure threshold**	
	$2_{\_Total}$: Log-linear, Ref 5.8	$2_{\_No\ Dust}$: Log-linear, Ref 5.8	$3_{\_Total}$: Linear, Ref 2.1	$3_{\_No\ Dust}$: Linear, Ref 0.8	$4_{\_Total}$: Log-linear, Ref 2.1	$4_{\_No\ Dust}$: Log-linear, Ref 0.8	5: Linear, Ref 5.8, Max 30	6: Linear, Ref 5.8, Max Hybrid
AFR-D	29 (18-39)	0 (0-0)	49 (28-70)	8 (5-12)	126 (79-172)	58 (36-80)	25 (14-35)	25 (14-35)
AFR-E	50 (31-70)	0 (0-0)	119 (67-171)	127 (72-183)	365 (230-499)	519 (329-703)	23 (13-33)	23 (13-33)
AMR-A	186 (116-256)	155 (96-213)	182 (104-260)	184 (105-262)	416 (264-562)	534 (343-716)	110 (62-158)	110 (62-158)
AMR-B	68 (42-93)	40 (25-55)	95 (54-136)	86 (49-123)	254 (161-346)	325 (206-440)	41 (23-59)	41 (23-59)
AMR-D	20 (12-27)	15 (10-21)	22 (12-31)	23 (13-33)	55 (35-74)	73 (47-98)	11 (6-16)	11 (6-16)
EMR-B	90 (57-121)	2 (1-2)	97 (56-135)	18 (10-26)	136 (88-180)	79 (50-107)	80 (46-112)	83 (48-116)
EMR-D	401 (256-539)	0 (0-1)	476 (281-656)	65 (37-94)	568 (369-751)	292 (185-397)	374 (218-522)	426 (250-590)
EUR-A	387 (244-529)	262 (164-360)	376 (215-532)	305 (174-433)	707 (452-950)	800 (515-1069)	275 (157-392)	275 (157-392)
EUR-B	180 (113-245)	90 (56-124)	172 (99-243)	114 (65-163)	319 (204-428)	325 (209-436)	128 (73-182)	128 (73-182)
EUR-C	205 (128-282)	117 (73-162)	212 (120-303)	189 (107-271)	507 (322-687)	622 (398-837)	117 (66-169)	117 (66-169)
SEAR-B	213 (134-291)	183 (115-250)	216 (124-306)	201 (115-284)	405 (259-545)	482 (311-642)	156 (89-222)	156 (89-222)
SEAR-D	124 (76-172)	0 (0-0)	310 (175-445)	166 (94-240)	952 (599-1301)	902 (567-1234)	56 (31-81)	56 (31-81)
WPR-A	113 (71-154)	86 (54-118)	110 (63-156)	92 (53-131)	204 (130-274)	236 (152-315)	82 (47-117)	80 (46-114)
WPR-B	1526 (978-2048)	1352 (865-1817)	2008 (1202-2727)	1820 (1082-2487)	2298 (1493-3042)	2638 (1727-3466)	1161 (674-1626)	1631 (966-2237)
World	3702 (2341-5034)	1840 (1158-2515)	4199 (2436-5881)	2723 (1565-3849)	7355 (4708-9878)	7560 (4846-10142)	2787 (1602-3937)	3030 (1753-4256)

Table 6.17 Attributable number of 2004 adult cardiopulmonary disease (CPD) deaths due to $PM_{2.5}$ (95% CIs)

WHO Subregion	Number of adult CPD deaths (000s) associated with $PM_{2.5}$							
	Selection of C-R function		Theoretical minimum				Maximum exposure threshold	
	2 Total Log-linear, Ref 5 8	2 _No Dust Log-linear, Ref 5 8	3 _Total Linear, Ref 2 1	3 _No Dust Linear, Ref 0 8	4 _Total Log-linear, Ref 2 1	4 No Dust Log-linear, Ref 0.8	5 Linear, Ref 5 8, Max 30	6 Linear, Ref 5 8, Max Hybrid
AFR-D	10 (4-13)	0 (0-0)	21 (13 - 28)	4 (2 - 6)	57 (38 - 74)	28 (19 - 38)	9 (6-12)	9 (6-12)
AFR-E	17 (11-23)	0 (0-0)	41 (26 - 56)	44 (27 - 60)	121 (81 - 158)	169 (115 - 219)	8 (5-11)	8 (5-11)
AMR-A	114 (76-150)	94 (63-125)	113 (71 - 154)	114 (72 - 155)	247 (169 - 318)	313 (217 - 399)	69 (43-95)	69 (43-95)
AMR-B	37 (25-49)	20 (14-27)	56 (35 - 76)	50 (31 - 68)	146 (99 - 190)	184 (125 - 238)	23 (14-31)	23 (14-31)
AMR-D	9 (6-12)	7 (5-9)	10 (7 - 14)	11 (7 - 15)	25 (17 - 32)	32 (22 - 42)	5 (3-7)	5 (3-7)
EMR-B	65 (44-83)	1 (1-2)	71 (46 - 93)	13 (8 - 18)	95 (67 - 120)	56 (38 - 73)	58 (37-77)	61 (40-81)
EMR-D	252 (174-323)	0 (0-0)	302 (199 - 391)	44 (27 - 60)	349 (246 - 437)	187 (127 - 242)	241 (157-317)	272 (178-355)
EUR-A	226 (152-295)	155 (104-203)	223 (142 - 300)	183 (116 - 247)	401 (276 - 512)	451 (313 - 571)	165 (104-224)	165 (104-224)
EUR-B	151 (102-197)	74 (49-97)	147 (94 - 198)	97 (61 - 131)	262 (180 - 334)	264 (182 - 336)	111 (70-150)	111 (70-150)
EUR-C	185 (123-245)	107 (71-142)	195 (122 - 265)	175 (109 - 238)	446 (304 - 576)	542 (373 - 693)	109 (68-150)	109 (68-150)
SEAR-B	104 (70-136)	87 (59-114)	111 (71 - 150)	102 (65 - 137)	208 (143 - 266)	241 (168 - 306)	78 (49-105)	78 (49-105)
SEAR-D	91 (60-122)	0 (0-0)	232 (144 - 318)	125 (77 - 173)	684 (460 - 894)	649 (436 - 849)	42 (26-58)	42 (26-58)
WPR-A	67 (45-88)	52 (35-68)	67 (43 - 90)	57 (36 - 76)	119 (82 - 152)	136 (95 - 173)	50 (32-68)	50 (32-68)
WPR-B	1222 (846-1556)	1096 (757-1398)	1636 (1106 - 2075)	1498 (1004 - 1916)	1768 (1246 - 2211)	1999 (1424 - 2477)	955 (618-1263)	1302 (865-1680)
World	2428 (1642-3153)	1208 (814-1578)	2818 (1821 - 3734)	1846 (1179 - 2476)	4755 (3277 - 6075)	4866 (3359 - 6209)	1867 (1191-2504)	2028 (1305-2699)

Table 6.18 Attributable number of 2004 adult lung cancer (LC) deaths due to $PM_{2.5}$ (95% CIs)

WHO Subregion	Number of adult LC deaths (00s) associated with $PM_{2.5}$							
	Selection of C-R function		Theoretical minimum				Maximum exposure threshold	
	$2_{\_Total}$: Log-linear, Ref 5.8	$2_{\_No\ Dust}$: Log-linear, Ref 5.8	$3_{\_Total}$: Linear, Ref 2.1	$3_{\_No\ Dust}$: Linear, Ref 0.8	$4_{\_Total}$: Log-linear, Ref 2.1	$4_{\_No\ Dust}$: Log-linear, Ref 0.8	5: Linear, Ref 5.8, Max 30	6: Linear, Ref 5.8, Max Hybrid
AFR-D	1 (1-1)	0 (0-0)	2 (1-4)	0 (0-1)	7 (4-10)	4 (2 - 5)	1 (0-1)	1 (0-1)
AFR-E	3 (2-5)	0 (0-0)	8 (3-12)	8 (4-13)	24 (13-34)	33 (18 - 46)	2 (1-2)	2 (1-2)
AMR-A	217 (114-314)	181 (95-264)	213 (92-326)	216 (93-330)	468 (256-654)	592 (331 - 810)	130 (56-202)	130 (56-202)
AMR-B	22 (12-32)	11 (6-16)	33 (14-51)	29 (12-44)	88 (47 -125)	109 (59 - 153)	13 (6-21)	13 (6-21)
AMR-D	4 (2-6)	3 (2-5)	4 (2-7)	5 (2-7)	10 (6 - 14)	13 (7 -18)	2 (1-4)	2 (1-4)
EMR-B	18 (10-26)	0 (0-0)	20 (9-29)	4 (2-6)	27 (15 - 36)	16 (8 - 22)	16 (7-24)	17 (8-25)
EMR-D	73 (40-100)	0 (0-0)	86 (40-121)	13 (5-20)	100 (57 - 133)	54 (29 - 76)	69 (31-100)	77 (36-111)
EUR-A	362 (194-517)	252 (134-363)	353 (156-530)	291 (127-440)	636 (353 - 875)	714 (402 - 971)	263 (114-400)	263 (114-400)
EUR-B	120 (64-172)	79 (42-114)	115 (51-174)	91 (40-139)	208 (116 - 287)	229 (129 - 312)	86 (37-132)	86 (37-132)
EUR-C	87 (46-127)	52 (27-75)	90 (39-139)	81 (35-124)	206 (112 - 288)	249 (138 - 343)	52 (22-80)	52 (22-80)
SEAR-B	93 (50-131)	82 (44-117)	91 (40-136)	86 (38-130)	157 (87 - 215)	185 (105 - 250)	70 (30-105)	70 (30-105)
SEAR-D	24 (12-36)	0 (0-0)	60 (25-93)	32 (14-51)	178 (95 - 254)	169 (90 - 242)	11 (5-17)	11 (5-17)
WPR-A	113 (61-161)	87 (46-125)	111 (49-166)	94 (41-142)	197 (110 - 271)	226 (127 - 307)	83 (36-127)	83 (36-127)
WPR-B	1208 (675-1655)	1107 (615-1524)	1550 (755-2127)	1423 (683-1978)	1673 (966 -2225)	1875 (1101 - 2456)	958 (434-1402)	1285 (608-1808)
World	1808 (979-2553)	976 (523-1392)	2040 (923-2995)	1386 (615-2073)	3434 (1910 -4726)	3552 (1984 - 4871)	1376 (609-2060)	1495 (671-2209)

Table 6.19 Attributable number of adult ischemic heart disease (IHD) deaths (95% CIs)

WHO Subregion	Number of adult IHD deaths (000s) associated with $PM_{2.5}$							
	Selection of C-R function		Theoretical minimum				Maximum exposure threshold	
	2_{Total}: Log-linear, Ref 5.8	$2_{\_No\ Dust}$: Log-linear, Ref 5.8	$3_{\_Total}$: Linear, Ref 2.1	$3_{\_No\ Dust}$: Linear, Ref 0.8	4_{Total}: Log-linear, Ref 2.1	$4_{\_No\ Dust}$: Log-linear, Ref 0.8	5: Linear, Ref 5.8, Max 30	6: Linear, Ref 5.8, Max Hybrid
AFR-D	1 (1-1)	0 (0-0)	5 (4 - 7)	2 (1 - 2)	20 (14 - 26)	12 (8 - 15)	1 (0-1)	1 (0-1)
AFR-E	8 (6-10)	0 (0-0)	19 (12 - 25)	20 (13 - 27)	52 (38 - 65)	70 (52 - 85)	4 (2-5)	4 (2-5)
AMR-A	113 (80-142)	95 (67-120)	113 (76 - 147)	114 (77 - 149)	229 (170 - 277)	280 (212 - 331)	71 (47-93)	71 (47-93)
AMR-B	32 (23-40)	18 (13-22)	44 (29 - 57)	39 (26 - 51)	103 (76 - 127)	125 (92 - 151)	20 (14-27)	20 (14-27)
AMR-D	4 (3-5)	3 (2-4)	5 (3 - 6)	5 (3 - 7)	11 (8 - 14)	14 (11 - 17)	2 (2-3)	2 (2-3)
EMR-B	63 (47-76)	3 (2-4)	70 (50 - 85)	16 (10 - 21)	85 (66 - 99)	56 (41 - 68)	59 (41-73)	62 (45-77)
EMR-D	205 (154-245)	1 (1-2)	238 (174 - 286)	41 (27 - 55)	265 (207 - 307)	159 (116 - 194)	197 (141-243)	219 (158-266)
EUR-A	188 (136-232)	137 (98-170)	188 (129 - 240)	159 (108 - 205)	313 (236 - 374)	348 (266 - 410)	142 (96-183)	142 (96-183)
EUR-B	136 (99-169)	60 (40-75)	134 (92 - 171)	84 (56 - 109)	220 (166 - 261)	212 (160 - 252)	104 (70-134)	104 (70-134)
EUR-C	216 (153-272)	132 (93-168)	226 (152 - 295)	204 (137 - 268)	475 (351 - 576)	560 (421 - 669)	132 (88-175)	132 (88-175)
SEAR-B	64 (46-79)	53 (39-66)	69 (47 - 88)	63 (43 - 80)	120 (90 - 144)	135 (103 - 160)	48 (33-63)	48 (33-63)
SEAR-D	74 (51-96)	0 (0-0)	185 (122 - 246)	102 (66 - 136)	514 (371 - 637)	490 (353 - 609)	35 (22-47)	35 (22-47)
WPR-A	30 (21-37)	23 (17-29)	31 (21 - 39)	26 (18 - 34)	52 (39 - 63)	59 (45 - 70)	23 (15-29)	23 (15-29)
WPR-B	353 (267-421)	314 (237-375)	438 (331 - 514)	409 (305 - 486)	498 (387 - 578)	550 (434 - 630)	285 (201-355)	362 (266-434)
World	1568 (1147-1921)	782 (562-969)	1806 (1269 - 2261)	1211 (831 - 1550)	2950 (2217 - 3528)	3012 (2268 - 3595)	1231 (849-1565)	1314 (918-1651)

6.3.4 Summary of Analyses

Overall, the subregions with the highest country-level concentrations were most sensitive to the 8 sensitivity scenarios. This was particularly the case for those subregions with country-level concentrations greater than 30μg/m^3 such as EMR-B/D and WPR-B.

Table 6.20 provides a summary of attributable numbers of global adult all cause, lung cancer, cardiopulmonary disease and ischemic heart disease deaths (000s) due to $PM_{2.5}$, under all 10 scenarios. Percentage changes in estimates were provided for each scenario compared to the base case for $PM_{2.5\_Total}$.

Table 6.20 Attributable number of global adult all cause (AC), lung cancer (LC), cardiopulmonary disease (CPD) and ischemic heart disease (IHD) deaths (000s) in 2004 due to $PM_{2.5}$, under 10 scenarios (% changes in estimates compared to the base case for $PM_{2.5\_Total}$)

Sensitivity Scenario	Attributable Deaths (000s) (% Change)[a]			
	AC	CPD	LC	IHD
$1_{\_Total}$: $PM_{2.5\_Total}$, Linear, Ref 5.8	3084	2077	152	1331
$1_{\_No\ Dust}$: $PM_{2.5\_No\ Dust}$, Linear, Ref 5.8	1357 (-56)	926 (-55)	74 (-51)	588 (-56)
$2_{\_Total}$: $PM_{2.5\_Total}$, Log-linear, Ref 5.8	3702 (20)	2428 (17)	181 (19)	1568 (18)
$2_{\_No\ Dust}$: $PM_{2.5\_No\ Dust}$, Log-linear, Ref 5.8	1840 (-40)	1208 (-42)	98 (-36)	782 (-41)
$3_{\_Total}$: $PM_{2.5\_Total}$, Linear, Ref 2.1	4199 (36)	2818 (36)	204 (34)	1806 (36)
$3_{\_No\ Dust}$: $PM_{2.5\_No\ Dust}$, Linear, Ref 0.8	2723 (-12)	1846 (-11)	139 (-9)	1211 (-9)
$4_{\_Total}$: $PM_{2.5\_Total}$, Log-linear, Ref 2.1	7355 (138)	4755 (129)	343 (126)	2950 (122)
$4_{\_No\ Dust}$: $PM_{2.5\_No\ Dust}$, Log-linear, Ref 0.8	7560 (145)	4866 (134)	355 (134)	3012 (126)
5: $PM_{2.5\_Total}$, Linear, Ref 5.8, Max 30	2787 (-10)	1867 (-10)	138 (-9)	1231 (-8)
6: $PM_{2.5\_Total}$, Linear, Ref 5.8, Max Hybrid	3030 (-2)	2028 (-2)	150 (-1)	1314 (-1)

Percent changes associated with each scenario compared to the base case were similar across the four causes of mortality. Removal of the dust component of $PM_{2.5}$ resulted in a 51-56% decrease in the number of global deaths attributable to $PM_{2.5}$ across the four causes of mortality, while maximizing the risk at 30μg/m^3 as well as at the point where the linear and log-linear models intersect resulted in smaller percent decreases in the number of global deaths attributable $PM_{2.5}$ (≤10%).

The log-linear concentration-response functions for $PM_{2.5\_Total}$ increased the attributable numbers of deaths across all four causes of mortality by roughly 20% when the reference value was the same as the base case, and by more than 100% when the reference value was set to 2.1μg/m^3. Decreasing the reference value to 2.1μg/m^3 alone, not incorporating the log-linear function, produced smaller increases of 34-36% in attributable number of death estimates. Overall, the log-linear functions resulted in higher global attributable numbers of deaths for all four causes of mortality when compared to equivalent linear counterparts.

6.3.5 Comparison with the 2000 GBD for Urban Air Pollution

The attributable fractions of mortality derived in this thesis were larger than those derived in the previous GBD. Table 6.21 shows a comparison of world and subregional attributable fractions using the different input factors employed in this thesis versus the previous GBD for urban air pollution.

The risk coefficient for the association between lung cancer and $PM_{2.5}$ increased from 0.00789 in the previous assessment to 0.01328 in the current analysis. Similarly, the risk coefficient for cardiopulmonary disease increased from 0.00575 in the previous GBD for urban air pollution to 0.01204 in the current work. Choice of reference exposure was another factor contributing to the differences observed for the attributable fractions in the current work versus those presented in the previous GBD for urban air pollution. In their base case assessment, the previous GBD for urban air pollution used the lowest observed city-level concentration in the 1979-1983 exposure data used to derive the risk coefficients, 7.5μg/m^3. As previously discussed, this thesis used the lowest observed city-level concentration in the 1999-2000 exposure data used to derive the risk coefficients, 5.8μg/m^3. When the risk coefficients as well as reference and maximum exposures from the 2000 GBD for urban air pollution are applied to the $PM_{2.5}$ concentration estimates employed in this thesis, AF estimates decrease by roughly half (column 3 for respective lung cancer and cardiopulmonary disease assessments).

Table 6.21 also shows a scenario for the AF estimates from the previous GBD whereby the rural population was considered to be exposed to urban air pollution (column 2 for respective lung cancer and cardiopulmonary disease assessments). Conversely, the previous GBD was focused on calculating mortality attributable to urban air pollution; and, in their assessment, the rural population was treated as unexposed to urban $PM_{2.5}$ pollution. Since the rural population would not have had the same exposure as the urban population to urban $PM_{2.5}$ pollution, the scenario presented in Table 6.21 is likely overestimating the true attributable fraction associated with urban air pollution in rural settings. However, treating this group as completely unexposed to urban air pollution likely underestimates the AF. This comparison was included for reference, and shows that AF estimates increase by more than double when the rural population is included in the assessment.

Table 6.21 Attributable fractions of lung cancer (AF_{LC}) and cardiopulmonary disease (AF_{CPD}) mortality derived under various alternative scenarios

	AF_{LC} Associated with $PM_{2.5}$				**AF_{CPD} Associated with $PM_{2.5}$**			
	2000 GBD for Urban Air Pollution		Current Analysis		2000 GBD for Urban Air Pollution		Current Analysis	
World	**5.0**	**13.3**	**6.2**	**11.5**	**3.0**	**9.8**	**4.4**	**10.2**
AFR-D	*5.0*	*17.4*	*0.4*	*0.8*	*2.0*	*12.9*	*0.5*	*1.2*
AFR-E	*2.0*	*9.1*	*0.0*	*1.1*	*1.0*	*6.6*	*0.0*	*1.0*
AMR-A	*3.0*	*3.8*	*2.9*	*7.0*	*2.0*	*2.8*	*2.2*	*6.4*
AMR-B	*4.0*	*8.5*	*0.9*	*2.5*	*3.0*	*6.2*	*0.7*	*2.3*
AMR-D	*6.0*	*13.3*	*1.9*	*5.3*	*3.0*	*9.7*	*1.2*	*4.3*
EMR-B	*4.0*	*9.5*	*13.4*	*23.2*	*3.0*	*7.0*	*10.0*	*21.3*
EMR-D	*8.0*	*23.6*	*18.7*	*31.0*	*4.0*	*17.6*	*14.0*	*28.6*
EUR-A	*2.0*	*4.2*	*6.2*	*12.2*	*1.0*	*3.1*	*4.5*	*11.0*
EUR-B	*5.0*	*12.1*	*6.3*	*12.4*	*3.0*	*8.9*	*4.8*	*11.6*
EUR-C	*3.0*	*6.1*	*2.3*	*6.0*	*2.0*	*4.4*	*1.6*	*5.3*
SEAR-B	*6.0*	*26.6*	*7.1*	*13.6*	*4.0*	*20.0*	*3.7*	*9.1*
SEAR-D	*4.0*	*21.4*	*0.0*	*1.1*	*3.0*	*16.0*	*0.0*	*1.0*
WPR-A	*4.0*	*6.6*	*6.2*	*11.9*	*3.0*	*4.9*	*4.5*	*10.8*
WPR-B	*10.0*	*23.7*	*20.3*	*33.3*	*6.0*	*17.8*	*14.1*	*28.4*
Risk Coefficients		**0.00789**		**0.01328**		**0.00575**		**0.01204**
Source of Ambient $PM_{2.5}$	Urban: Global Model of Ambient Particulates		Global: Satellite Imagery		Urban: Global Model of Ambient Particulates		Global: Satellite Imagery	
Reference Exposure (X_0)		7.5μg/m^3		5.8μg/m^3		7.5μg/m^3		5.8μg/m^3
Maximum Exposure		50μg/m^3		None		50μg/m^3		None
Unexposed Population	Rural		None		Rural		None	

[a] Highlighted cells represent base case scenarios

6.3.6 Impact Assessment: Removal of Countries Lacking Mortality Data

Despite having satellite data for 231 countries, subregional and global estimates of relative risk and attributable fractions of mortality associated with $PM_{2.5}$ were based on 132 countries for which there was $PM_{2.5}$ *and* mortality data. The impact of excluding the 99 countries lacking mortality data from the analysis was assessed. Mean weighted subregional $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ concentrations based on all 231 countries with $PM_{2.5}$ data were compared to concentrations for those 132 countries that had both $PM_{2.5}$ and mortality data (Table 6.22). The 132 countries for which there exists $PM_{2.5}$ and mortality data represent 60% of the population for all 231 countries with $PM_{2.5}$ data. The mean weighted world $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ concentrations for the 132 countries with mortality data were 1.6μg/m^3 and 3.3μg/m^3 respectively higher than those for all of the 231 countries. The subregional ranges of $PM_{2.5\_Total}$ were the same for 6 subregions (AMR-A/B, EUR-B/C, SEAR-B, WPR-A) under both scenarios, while the weighted means were the same for 5 subregions (AMR-A/B, EUR-B/C, WPR-A). Of the 9 subregions where a difference in mean $PM_{2.5\_Total}$ concentration was found between the two scenarios, 3 (AMR-D, EMR-B, EUR-A) had a differences of ≤1μg/m^3 and 3 (AFR-E, SEAR-B, WPR-B) had a difference of between 2-3μg/m^3. The remaining 3 subregions, EMR-D, SEAR-D, and AFR-D, had larger respective differences of 6.3μg/m^3, 13.2μg/m^3, and 18.4μg/m^3. The subregional ranges of $PM_{2.5\_No\ Dust}$ were the same for half of the subregions (AMR-A/B/D, EUR-B/C, SEAR-B, WPR-A) under both scenarios, while the weighted means were the same for 5 subregions (AMR-A/B, EUR-B/C, WPR-A). Of the 8 subregions where a difference in mean $PM_{2.5\_Total}$ concentration was found between the two scenarios, 5 (AFR-E, AMR-D, EMR-B, EUR-A, SEAR-B) had a differences of ≤1μg/m^3 and 2 (AFR-D, EMR-D) had differences between 2-3μg/m^3. Subregion SEAR-D had the largest difference of 15.6μg/m^3. Overall, $PM_{2.5}$ concentrations did not change for most subregions when the 99 countries lacking mortality data were excluded from the estimates.

Table 6 22 Comparıson of mean weıghted subregıonal $PM_{2\ 5\_Total}$ and $PM_{2\ 5\_No\ Dust}$ concentratıons (µg/m³) for all 231 countrıes wıth $PM_{2\ 5}$ data versus those 132 countrıes that had both $PM_{2\ 5}$ and mortalıty data

WHO Subregion	**Countries with $PM_{2\ 5}$ Data**		**Countries with $PM_{2\ 5}$ + Mortality Data**		**Mean Weighted $PM_{2\ 5\_Total}$ Concentrations (µg/m³) (Range)**		**Mean Weighted $PM_{2\ 5\_No\ Dust}$ Concentrations (µg/m³) (Range)**	
	Number	Populatıon Coverage (mıllıons)	Number	Populatıon Coverage (mıllıons)	Wıth $PM_{2\ 5}$ Data	Wıth $PM_{2\ 5}$ + Mortalıty Data	Wıth $PM_{2\ 5}$ Data	Wıth $PM_{2\ 5}$ + Mortalıty Data
AFR-D	29	325	5	2	20 2 (2 1 - 41 8)	7 0 (2 8 - 23 6)	3 4 (0 8 - 7 3)	1 3 (1 0 - 4 4)
AFR-E	20	384	2	59	8 7 (4 3 - 19 3)	6 2 (4 6 - 6 7)	5 7 (2 4 - 10 7)	5 3 (4 1 - 5 7)
AMR-A	3	339	3	339	11 3 (9 3 - 11 6)		10 1 (5 2 - 10 4)	
AMR-B	41	462	41	462	7 9 (3 4 - 14 3)		5 9 (1 1 - 13 1)	
AMR-D	6	78	5	68	9 1 (6 1 - 11 9)	9 5 (6 5 - 11 9)	7 9 (4 5 - 11 2)	8 2 (4 5 - 11 2)
EMR-B	12	150	5	96	25 6 (17 2 - 41 4)	24 4 (22 8 - 41 4)	4 3 (2 5 - 6 7)	4 7 (4 2 - 6 7)
EMR-D	10	386	2	232	31 9 (9 4 - 40 3)	38 2 (33 7 - 40 3)	8 2 (1 9 - 14 5)	11 4 (4 7 - 14 5)
EUR-A	35	413	26	413	15 8 (3 0 - 23 3)	15 5 (3 7 - 23 3)	11 7 (1 4 - 17 5)	11 5 (1 6 - 17 5)
EUR-B	16	223	16	223	16 4 (11 8 - 24 7)		8 8 (3 3 - 14 4)	
EUR-C	9	235	9	235	10 3 (7 0 - 16 0)		8 1 (4 7 - 12 9)	
SEAR-B	3	305	2	85	13 1 (6 7 - 17 5)	15 1 (6 7 - 17 5)	11 5 (3 7 - 15 5)	12 9 (3 7 - 15 5)
SEAR-D	8	1,330	1	0	24 99 (3 9 - 29 2)	6 6	18 78 (2 5 - 19 6)	3 2
WPR-A	7	155	5	155	14 8 (2 9 - 19 5)		11 4 (1 2 - 18 0)	
WPR-B	32	1,580	10	1,450	44 9 (2 3 - 51 5)	47 3 (3 5 - 51 5)	39 0 (0 8 - 47 4)	41 0 (1 2 - 47 4)
World	**231**	**6,370**	**132**	**3,820**	**24.7**	**26.3**	**17.97**	**21.25**

In addition to comparing subregional $PM_{2.5}$ concentrations based on all 231 countries with $PM_{2.5}$ data versus those 132 countries that had both $PM_{2.5}$ and mortality data, a similar analysis was undertaken for subregional relative risk estimates. Subregional relative risk estimates of all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease were compared for the total set of 231 countries with satellite data versus the set of 132 countries to be included in the final analysis (Tables 6.23-6.26). Comparing the two scenarios, relative risk estimates for all cause and lung cancer mortality associated with $PM_{2.5\_Total}$ were the same for 6 subregions (AMR-A/B, EUR-A/B/C, WPR-A) and significantly different for 2 subregions (AFR-D, SEAR-D), while relative risk estimates for cardiopulmonary and ischemic heart disease mortality associated with $PM_{2.5\_Total}$ were the same for 6 subregions (AMR-A/B, EUR-A/B/C, WPR-A) and significantly different for 3 subregions (AFR-D/E, SEAR-D). Similarly, comparing the two scenarios, relative risk estimates for all cause, cardiopulmonary, lung cancer, and ischemic heart disease mortality associated with $PM_{2.5\_No\ Dust}$ were the same for 9, 9, 8, and 7 subregions respectively, and significantly different for 1 subregion, AFR-E or SEAR-D depending on the cause of mortality. Overall, the changes in relative risk estimates associated with excluding countries lacking mortality data were larger for $PM_{2.5\_Total}$ than $PM_{2.5\_No\ Dust}$, and there appeared to be no trend regarding the absolute size or direction of the change by subregion or cause of mortality.

Four simple linear regressions were run to determine if the decrease in the number of countries per subregion was related to the absolute difference in all cause, cardiopulmonary, lung cancer, and ischemic heart disease relative risk estimates associated with $PM_{2.5\_Total}$ before and after removal of countries lacking mortality data. The null hypothesis that the slope of the line was equal to zero was not rejected for all four regressions ($P>0.05$), thus, the differences seen in subregional RRs are not sufficiently explained by the number of countries excluded per subregion, but rather is likely the result of excluding a few countries with outlying mean exposures.

Of the 3 subregions that were associated with the largest differences in $PM_{2.5}$ concentrations with removal of the 99 countries lacking mortality data (EMR-D, SEAR-D, and AFR-D), only SEAR-D and AFR-D were observed to have significantly different relative risks of mortality between the two scenarios.

Table 6.23 Relative risk of all cause mortality (RR_{AC}) for all 231 countries with $PM_{2.5}$ data versus those 132 countries that had both $PM_{2.5}$ and mortality data (95% confidence intervals)

WHO Subregion	**RR_{AC} Associated with $PM_{2.5\_Total}$ (95% CI)[a,b]**		**RR_{AC} Associated with $PM_{2.5\_No\ Dust}$ (95% CI)[a,b]**	
	Countries with $PM_{2.5\_Total}$ Data	Countries with $PM_{2.5\_Total}$ + Mortality Data	Countries with $PM_{2.5\_No\ Dust}$ Data	Countries with $PM_{2.5\_No\ Dust}$ + Mortality Data
AFR-D	1.12 (1.06-1.17)	1.02 (1.01-1.04)	1.00 (1.00-1.00)	
AFR-E	1.02 (1.01-1.03)	1.01 (1.00-1.01)	1.01 (1.00-1.01)	1.00 (1.00-1.00)
AMR-A	1.04 (1.02-1.06)		1.03 (1.02-1.05)	
AMR-B	1.02 (1.01-1.03)		1.01 (1.01-1.02)	
AMR-D	1.03 (1.01-1.04)	1.03 (1.02-1.04)	1.02 (1.01-1.03)	
EMR-B	1.16 (1.09-1.24)	1.15 (1.08-1.23)	1.00 (1.00-1.00)	
EMR-D	1.22 (1.12-1.33)	1.28 (1.15-1.42)	1.03 (1.02-1.04)	1.05 (1.03-1.07)
EUR-A	1.08 (1.04-1.11)		1.04 (1.02-1.07)	
EUR-B	1.08 (1.05-1.12)		1.02 (1.01-1.04)	
EUR-C	1.03 (1.02-1.05)		1.02 (1.01-1.03)	
SEAR-B	1.06 (1.03-1.08)	1.07 (1.04-1.11)	1.04 (1.02-1.07)	1.06 (1.03-1.09)
SEAR-D	1.18 (1.10-1.27)	1.01 (1.00-1.01)	1.09 (1.05-1.14)	1.00 (1.00-1.00)
WPR-A	1.07 (1.04-1.11)		1.05 (1.03-1.07)	
WPR-B	1.07 (1.18-1.53)	1.37 (1.19-1.57)	1.29 (1.15-1.44)	1.30 (1.16-1.47)

[a] Cells highlighted grey indicate a significant difference
[b] RRs were calculated using the base case scenarios for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ respectively

Table 6.24 Relative risk of cardiopulmonary disease mortality (RR_{CPD}) for all 231 countries with $PM_{2.5}$ data versus those 132 countries that had both $PM_{2.5}$ and mortality data (95% confidence intervals)

WHO Subregion	**RR_{CPD} Associated with $PM_{2.5\_Total}$ (95% CI)[a,b]**		**RR_{CPD} Associated with $PM_{2.5\_No\ Dust}$ (95% CI)[a,b]**	
	Countries with $PM_{2.5\_Total}$ Data	Countries with $PM_{2.5\_Total}$ + Mortality Data	Countries with $PM_{2.5\_No\ Dust}$ Data	Countries with $PM_{2.5\_No\ Dust}$ + Mortality Data
AFR-D	1.04 (1.02-1.06)	1.19 (1.11-1.28)	1.00 (1.00-1.00)	
AFR-E	1.01 (1.01-1.01)	1.04 (1.02-1.05)	1.01 (1.01-1.02)	1.00 (1.00-1.00)
AMR-A	1.07 (1.04-1.10)		1.05 (1.03-1.07)	
AMR-B	1.03 (1.02-1.04)		1.02 (1.01-1.03)	
AMR-D	1.05 (1.03-1.06)	1.04 (1.02-1.06)	1.03 (1.02-1.04)	
EMR-B	1.25 (1.15-1.37)	1.27 (1.16-1.39)	1.00 (1.00-1.00)	
EMR-D	1.48 (1.27-1.72)	1.37 (1.21-1.55)	1.04 (1.03-1.06)	1.07 (1.05-1.10)
EUR-A	1.12 (1.07-1.18)		1.07 (1.04-1.10)	
EUR-B	1.14 (1.08-1.19)		1.04 (1.02-1.05)	
EUR-C	1.06 (1.03-1.08)		1.03 (1.02-1.04)	
SEAR-B	1.12 (1.07-1.17)	1.09 (1.06-1.13)	1.07 (1.04-1.10)	1.09 (1.06-1.13)
SEAR-D	1.01 (1.01-1.01)	1.30 (1.18-1.45)	1.15 (1.09-1.22)	1.00 (1.00-1.00)
WPR-A	1.12 (1.07-1.17)		1.08 (1.05-1.11)	
WPR-B	1.65 (1.36-2.00)	1.60 (1.34-1.93)	1.50 (1.28-1.75)	1.53 (1.30-1.80)

[a] Cells highlighted grey indicate a significant difference
[b] RRs were calculated using the base case scenarios for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ respectively

Table 6.25 Relative risk of lung cancer mortality (RR_{LC}) for all 231 countries with $PM_{2.5}$ data versus those 132 countries that had both $PM_{2.5}$ and mortality data (95% confidence intervals)

WHO Subregion	**RR_{LC} Associated with $PM_{2.5\_Total}$ (95% CI)[a,b]**		**RR_{LC} Associated with $PM_{2.5\_No\ Dust}$ (95% CI)[a,b]**	
	Countries with $PM_{2.5\_Total}$ Data	Countries with $PM_{2.5\_Total}$ + Mortality Data	Countries with $PM_{2.5\_No\ Dust}$ Data	Countries with $PM_{2.5\_No\ Dust}$ + Mortality Data
AFR-D	1.21 (1.08-1.36)	1.04 (1.02-1.07)	1.00 (1.00-1.00)	
AFR-E	1.04 (1.02-1.07)	1.01 (1.00-1.02)	1.01 (1.01-1.02)	1.00 (1.00-1.00)
AMR-A	1.08 (1.03-1.12)		1.07 (1.02-1.09)	
AMR-B	1.04 (1.01-1.06)		1.03 (1.01-1.04)	
AMR-D	1.04 (1.02-1.07)	1.05 (1.02-1.08)	1.03 (1.01-1.05)	1.04 (1.01-1.06)
EMR-B	1.30 (1.12-1.52)	1.28 (1.11-1.48)	1.00 (1.00-1.00)	
EMR-D	1.41 (1.16-1.73)	1.54 (1.20-1.98)	1.05 (1.02-1.08)	1.08 (1.03-1.13)
EUR-A	1.14 (1.06-1.23)		1.08 (1.03-1.13)	
EUR-B	1.15 (1.06-1.25)		1.04 (1.02-1.07)	
EUR-C	1.06 (1.03-1.10)		1.03 (1.01-1.05)	
SEAR-B	1.10 (1.04-1.17)	1.13 (1.05-1.22)	1.08 (1.03-1.13)	1.11 (1.04-1.17)
SEAR-D	1.34 (1.13-1.59)	1.01 (1.00-1.02)	1.17 (1.07-1.28)	1.00 (1.00-1.00)
WPR-A	1.13 (1.05-1.22)		1.08 (1.03-1.14)	
WPR-B	1.68 (1.24-2.28)	1.73 (1.26-2.39)	1.56 (1.20-2.02)	1.60 (1.22-2.10)

[a] Cells highlighted grey indicate a significant difference
[b] RRs were calculated using the base case scenarios for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ respectively

Table 6.26 Relative risk of ischemic heart disease mortality (RR_{IHD}) for all 231 countries with $PM_{2.5}$ data versus those 132 countries that had both $PM_{2.5}$ and mortality data (95% confidence intervals)

WHO Subregion	**RR_{IHD} Associated with $PM_{2.5\_Total}$ (95% CI)[a,b]**		**RR_{IHD} Associated with $PM_{2.5\_No\ Dust}$ (95% CI)[a,b]**	
	Countries with $PM_{2.5\_Total}$ Data	Countries with $PM_{2.5\_Total}$ + Mortality Data	Countries with $PM_{2.5\_No\ Dust}$ Data	Countries with $PM_{2.5\_No\ Dust}$ + Mortality Data
AFR-D	1.45 (1.27-1.65)	1.08 (1.05-1.12)	1.00 (1.00-1.00)	
AFR-E	1.08 (1.05-1.11)	1.02 (1.01-1.02)	1.03 (1.02-1.04)	1.00 (1.00-1.00)
AMR-A	1.15 (1.09-1.20)		1.11 (1.07-1.16)	
AMR-B	1.07 (1.04-1.09)		1.04 (1.03-1.06)	
AMR-D	1.09 (1.06-1.12)	1.10 (1.06-1.14)	1.06 (1.04-1.08)	1.07 (1.04-1.09)
EMR-B	1.65 (1.38-1.96)	1.60 (1.36-1.89)	1.00 (1.00-1.00)	1.00 (1.00-1.01)
EMR-D	1.93 (1.53-2.44)	2.27 (1.70-3.02)	1.09 (1.06-1.13)	1.16 (1.10-1.23)
EUR-A	1.28 (1.17-1.39)		1.16 (1.10-1.22)	
EUR-B	1.31 (1.19-1.43)		1.08 (1.05-1.11)	
EUR-C	1.12 (1.08-1.17)		1.06 (1.04-1.08)	
SEAR-B	1.20 (1.13-1.28)	1.26 (1.16-1.37)	1.16 (1.10-1.22)	1.21 (1.13-1.29)
SEAR-D	1.74(1.43-2.12)	1.02 (1.01-1.03)	1.35 (1.21-1.49)	1.00 (1.00-1.00)
WPR-A	1.26 (1.16-1.37)		1.17 (1.11-1.23)	
WPR-B	2.69 (1.90-3.82)	2.85 (1.97-4.12)	2.32 (1.72-3.13)	2.43 (1.78-3.33)

[a] Cells highlighted grey indicate a significant difference
[b] RRs were calculated using the base case scenarios for $PM_{2.5\_Total}$ and $PM_{2.5\_No\ Dust}$ respectively

6.3.7 Impact Assessment: Removal of Countries with Outdated Mortality Data

As was discussed in the methods section, 17 countries had mortality data that were ≥10 years older than the year of the population data used to weight the $PM_{2.5}$ exposures, 2005. To explore the impact of including these 17 countries, base case subregional and global attributable fractions were re-calculated with these countries removed.

Table 6.27 compares the base case attributable fractions produced in this thesis to those derived when the 17 countries with mortality data older than 1995 were removed. Overall, the attributable fractions were not significantly different in this subsidiary analysis. The subregions where the AF point estimates changed by >1% for at least one cause of mortality were AFR-D, EMR-B, and EUR-B. At a global level, cardiopulmonary disease, lung cancer and ischemic heart disease had attributable fractions that changed by >1%. However, confidence intervals for all three sets of global AF estimates were not significantly different.

Since removal of these 17 countries did not produce base case AFs that were significantly different from those originally produced in the primary analysis, they remained in this work in order to capture the additional $PM_{2.5}$ data.

Table 6.27 Base case attributable fractions for all four air pollution causes of mortality associated with $PM_{2.5}$ as calculated in the primary analysis versus the scenario when 17 countries mortality data ≥10 years are removed

WHO Subregion	AF_{AC}		AF_{CPD}		AF_{LC}		AF_{IHD}	
	Primary Analysis	Removal of 17 Countries[a]	Primary Analysis	Removal of 17 Countries[a]	Primary Analysis	Removal of 17 Countries[a]	Primary Analysis	Removal of 17 Countries[a]
AFR-D	1.0 (0.6-1.4)	0.0 (0.0-0.0)	**1.2 (0.7-1.6)**	**0.0 (0.0-0.0)**	0.8 (0.3-1.1)	0.0 (0.0-0.0)	0.4 (0.3-0.5)	0.0 (0.0-0.0)
AFR-E	0.6 (0.4-0.9)		1.0 (0.6-1.4)		1.1 (0.5-1.8)		2.2 (1.4-2.9)	2.2 (1.5-3.0)
AMR-A	4.0 (2.3-5.8)		6.4 (4.0-8.7)		7.0 (3.0-10.9)		12.9 (8.5-17.0)	
AMR-B	1.6 (0.9-2.3)		2.3 (1.4-3.1)		2.5 (1.0-3.8)		5.9 (3.9-7.7)	
AMR-D	2.7 (1.5-3.9)		4.3 (2.7-5.9)		5.3 (2.2-8.2)		7.8 (5.1-10.3)	
EMR-B	13.8 (8.0-19.3)	1.8 (1.1-2.5)	21.3 (13.8-28.2)	4.2 (2.8-5.4)	23.2 (10.5-34.0)	5.9 (2.8-8.3)	43.1 (30.7-53.1)	58.3 (43.2-69.4)
EMR-D	18.9 (11.1-26.2)		28.6 (18.7-37.3)		31.0 (14.3-44.4)		50.6 (36.6-61.5)	50.5 (36.5-61.4)
EUR-A	7.0 (4.0-9.9)		11.0 (6.9-14.9)		12.2 (5.3-18.6)		21.5 (14.5-27.8)	
EUR-B	7.4 (4 2-10.6)	6.8 (3.9-9.7)	11.6 (7.3-15.7)	10.6 (6.7-14.4)	12.4 (5.4-18.9)	11.3 (4.9-17.2)	23.1 (15.6-29.8)	23.2 (15.7-30.0)
EUR-C	3.3 (1.9-4.7)		5.3 (3.3-7.2)		6.0 (2.6-9.3)		11.1 (7.4-14.7)	
SEAR-B	6.7 (3.8-9.4)		9.1 (5.8-12.3)		13.6 (5.9-20.6)		17.5 (11.9-22.6)	
SEAR-D	0.6 (0.3-0.9)		1.0 (0.6-1.3)		1.1 (0.4-1.7)		2.0 (1.3-2.7)	
WPR-A	6.9 (3.9-9.8)		10.8 (6.8-14.6)		11.9 (5.2-18.1)		17.4 (11.8-22.5)	
WPR-B	17.6 (10.5-23.9)	17 2 (10.3-23 4)	28.4 (19.1-36.2)	28.1 (18.9-35.8)	33.3 (16.1-46.0)	33.0 (15.9-45.6)	43.8 (33.0-51.6)	44.4 (33.4-52.2)
World	6.6 (3 8-9.2)	5.6 (3.2-7.8)	10.2 (6.6-13.5)	8.7 (5.7-11.6)	11.5 (5.2-17.0)	10.1 (4.6-14.9)	18.5 (13.0-23.2)	19.6 (13.9-24.4)

[a] AF differences greater than 1.0% are highlighted

7.0 DISCUSSION

The $PM_{2.5}$ concentrations employed in this thesis were obtained from two different satellite instruments, MISR and MODIS. Relative risks were calculated using pollution concentrations in conjunction with previously developed concentration-response functions for the association between $PM_{2.5}$ and four causes of mortality: all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease. Relative risk and mortality estimates were used to estimate the population fractions of mortality and expected number of deaths attributable to chronic $PM_{2.5}$ exposure.

It was estimated that 6.6% (95% confidence interval: 3.8-9.2) of all cause, 10.2% (6.6-13.5) of cardiopulmonary disease, 11.5% (5.2-17.0) of lung cancer, and 18.5% (13.0-23.2) of ischemic heart disease mortalities were attributable to the total component of $PM_{2.5}$. The global fraction of adult mortality attributable to the anthropogenic component of $PM_{2.5}$ was 2.9% (1.7-4.1) for all causes, 4.5% (2.9-6.0) for cardiopulmonary disease, 5.6% (2.5-8.3) for lung cancer, and 8.2% (5.6-10.4) for ischemic heart disease. In 2004, 3 million adult all cause, 2.1 million cardiopulmonary disease, 1.3 million ischemic heart disease, and 152,400 lung cancer deaths were attributable to $PM_{2.5\_Total}$, while 1.4 million all cause, 926,000 cardiopulmonary disease, 588,000 ischemic heart disease, and 73,500 lung cancer deaths were attributable to the anthropogenic component of $PM_{2.5}$.

7.1 Total versus Anthropogenic Components of $PM_{2.5}$

Removal of the dust component of $PM_{2.5}$ resulted in a 51-56% decrease in the number of global deaths attributable to $PM_{2.5}$ across the four causes of mortality under the base case. Decreases at the subregional levels varied greatly, with the largest decreases occurring for the African and Mediterranean regions and the smallest decrease occurring in the Western Pacific. The risk coefficients used in this thesis were based on air pollution measures from urban areas where $PM_{2.5}$ is primarily derived from human activities, and therefore may not be representative of the risks associated with the natural dust component of $PM_{2.5}$. Furthermore, the coefficients were derived based on $PM_{2.5}$ measures in the United States, a country with a relatively low dust component overall as seen by the small decrease in mean weighted ambient $PM_{2.5}$ with removal of its dust component. Thus, it is arguable that the risk coefficients employed in this thesis better represent the association between the anthropogenic component of $PM_{2.5}$ and mortality versus its total component, and ultimately, it may be most suitable to report on mortality due to $PM_{2.5\_No\ Dust}$ in this thesis.

7.2 Sensitivity Analyses

7.2.1 Concentration-Response Function

The exponential function deviates from the linear function at higher concentrations where the rate of risk increase with ambient $PM_{2.5}$ exposure becomes rather large; and, the point at which the exponential model deviates from the 'true' linear model is dependent upon the risk coefficient. Those air pollution causes of mortality with larger risk coefficients, such as ischemic heart disease, have a steeper exponential slope and deviate from the 'true' linear model at lower concentrations.

The log-linear model was introduced into the 2000 GBD for urban air pollution because it was believed to be a reasonable way to characterize excess risk at higher concentrations, such that the rate of increase, while still increasing monotonically with $PM_{2.5}$, decreases at higher concentrations,(9,80) as has been observed for daily mortality in time-series studies.(91,92)

The log-linear concentration-response functions, compared to their linear counterparts, produced higher world attributable fraction estimates across all scenarios and for all causes of mortality. The log-linear concentration-response functions for $PM_{2.5\_Total}$ increased the attributable numbers of global deaths across all four causes of mortality by roughly 20% when the reference value was the same as the base case, and by more than 100% when the reference value was set to 2.1 $\mu g/m^3$.

At the subregional level, the log-linear scenarios produced higher attributable fraction estimates compared to their linear equivalents for all four causes of mortality and across all subregions, except for the two subregions with the highest concentrations of $PM_{2.5}$, EMR-D and WPR-B. The shape of the log-linear function is such that risk increases in larger intervals at lower concentrations while allowing for a more gradual increase in risk at higher $PM_{2.5}$ concentrations. This type of function was proposed as an alternative to the linear model when modelling risk beyond the highest air pollution levels observed in epidemiological studies, where up to those levels, risk has been observed to increase linearly with $PM_{2.5}$. In the 2000 GBD for urban air pollution it was found that burden of disease estimates for subregions where exposure was relatively low were 63% higher in log-linear versus linear scenarios, while burden estimates for subregions with high exposures remained unchanged or were slightly reduced.(80) In this study, the substantially higher risk of mortality observed under log-linear scenarios compared to equivalent linear scenarios characterize this trend well. Since most countries had mean $PM_{2.5}$ concentrations that were below the levels observed in the ACS, the log-linear C-R function may over estimate risk associated with PM, particularly for the anthropogenic component of $PM_{2.5}$, or for regions with where ambient concentrations are less than 30μg/m^3.

7.2.2 Theoretical-Minimum Concentration

Selection of the theoretical-minimum or reference exposure was a critical part of this assessment as previous estimates of mortality attributable to $PM_{2.5}$ have been sensitive to this variable.(80,93) For the base case scenario, the theoretical-minimum value was set to 5.8μg/m^3, the lowest observed in the 1999-2000 ACS air pollution study.(63) However, since several country-level mean weighted $PM_{2.5}$ estimates were lower than 5.8μg/m^3, this presented an issue.

In this work, relative risks and attributable fractions are calculated relative to a single, mean, theoretical minimum value which has a defined relative risk of 1.00. However, due to inter-person variability, the risk at the theoretical minimum would not likely be 1.00 for all individuals. In fact, risk at the hypothetical theoretical-minimum exposure would be a distribution with a non-zero standard deviation with a mean of 1.00. However, for computational reasons, relative risks for a continuous exposure variable such as air pollution, are calculated relative to the mean of the theoretical-minimum, and relative risks for individuals with an exposure below the mean are typically set to 1.00.(87) This method was employed in this work. Sensitivity analysis has revealed that global attributable fractions estimated relative to the mean versus the full distribution of the theoretical-minimum-risk were up to 2% larger.(87) The discrepancy between the risk calculated in the current work versus the risk that would have been calculated in the case of treating the theoretical-minimum-risk exposure as a distribution would depend on both the steepness of the risk curve and the standard deviations of the current and theoretical-minimum-risk exposure distributions.

Decreasing the theoretical minimum from 5.8μg/m^3 to the lowest levels observed this study, 2.1μg/m^3 for $PM_{2.5\_Total}$ and 0.8μg/m^3 for $PM_{2.5\_No\ Dust}$, resulted in higher attributable fraction estimates. Compared to the base case, decreasing the reference value to 2.1μg/m^3 increased the estimate of number of deaths attributable to $PM_{2.5\_Total}$ by 34-36% across all four causes of mortality. However, this scenario is unrealistic as it presumes that $PM_{2.5\_Total}$ can be reduced to levels which are likely below naturally occurring background concentrations of $PM_{2.5}$ for many regions. So, while the reference value used in the base case scenario ignores any potential health benefits that may arise when reducing $PM_{2.5}$ concentrations below 5.8μg/m^3, it may be not be reasonable to model risk for concentrations below those which are naturally occurring; and, furthermore, the base case choice avoided extrapolating the concentration-response function below the concentrations observed in the epidemiological study from which the risk coefficients were derived.

7.2.3 Maximum Exposure Threshold

Extrapolation of risk beyond the highest $PM_{2.5}$ exposure levels observed in the ACS cohort, 30μg/m^3, involves making assumptions about the shape of the C-R function. The base case assumed that risk increases exponentially with ambient $PM_{2.5}$ concentrations for the entire range of country-level concentrations observed in this work. Maximizing the risk at 30μg/m^3 as well as at the point where the linear and log-linear models intersect resulted in small decreases in the number of global deaths attributable to $PM_{2.5}$ (≤10%).

Overall, maximizing risk did not have a large effect on the base case estimates since only three subregions had country-level concentrations above 30μg/m^3, and of these, only one had country-level concentrations higher than the concentration at which linear and log-linear models intersect.

7.3 Development of Methods

A major component of this thesis work was deciphering the methods employed in the 2000 GBD analysis. The following is an overview of the steps taken to develop methods, including all assumptions made when the methods of the 2000 GBD were unclear.

7.3.1. Derivation of Subregional Relative Risks

The equation for calculating subregion-specific relative risks was outlined in the detailed chapter of the 2000 GBD for urban air pollution:

$$RR_{ik} = \exp[\beta_i * (C_k - 7.5)] \qquad \textit{(Equation 5)}$$

where:

- RR_{ik} is the subregion-specific relative risk for outcome 'i' in subregion 'k' related to $PM_{2.5}$;
- C_k is the subregion-specific population-weighted mean concentration of $PM_{2.5}$, and,
- β_i is the slope of the concentration-response function for $PM_{2.5}$. (80)

In a validation process to ensure that these methods could be replicated, re-calculation of subregional relative risks in the 2000 GBD was undertaken using data presented in the detailed chapter. However, replication of results was not initially possible, as it was determined via personal communication with the lead author that in fact the methodology they employed was slightly different from what was presented in the chapter. In *Equation 5*, where it calls for subtracting the theoretical minimum level from the *subregional* mean $PM_{2.5}$ concentration, what was actually done was to first subtract the theoretical minimum from each of the *city-specific* $PM_{2.5}$ estimates and then use the full-distribution of city-specific estimates to develop the subregional population-weighted means (A. Cohen, personal communication). The methods employed in this thesis reflect this information.

7.3.2 Derivation of Fractions of Mortality Attributable to $PM_{2.5}$

As with relative risk estimation, a validation process was undertaken to ensure that the methods outlined in the 2000 GBD for urban air pollution for calculation of the subregional and global attributable fractions (AF) could be replicated in this work. However, several issues arose during this process. First, there was some confusion as to how and if the 2000 GBD for urban air pollution actually calculated PAFs for each of the 224 age-sex-subregional categories, as is specified in their methodology. Since the study only presented risk coefficients for the total population, and since such refined estimates have not been presented elsewhere, it was assumed that age and sex specific risk coefficients did not exist for all 224 cells. If this assumption is true, using risk coefficients for the total population to calculate PAFs broken down by age and sex would not have been a worthwhile exercise, since the relative risks used to calculate the PAFs would have been the same across all age-sex strata. Confirmation of the exact methodology was sought from the lead author; however, calculation of AFs was an independent undertaking that occurred at an analytical coordinating centre, and no final response was obtained. Therefore, as a means to determine the methodology employed to calculate AFs, several alternative scenarios were explored that did not involve calculating PAFs for age-sex specific categories.

This validation process, while time consuming, eventually resulted in uncovering a method which allowed for reproduction of the AFs for lung cancer and cardiopulmonary disease mortality that are presented in the detailed chapter of the 2000 GBD for urban air pollution. The following is a brief description of the exploratory work which led to the discovery of the method, which, while it includes key findings, does not provide full details of the process.

Equation 3, which was employed in the current thesis to derive AFs, was initially explored as the method by which subregional AFs were produced in the 2000 GBD for urban air pollution. However, when subregional relative risks were plugged into *Equation 3*, the resulting attributable fractions were substantially higher than those presented in the detailed chapter of the 2000 GBD for urban air pollution, as is presented in Table 7.1. This comparison indicated that *Equation 3* was not the methodology used to calculate AFs.

Table 7.1 Relative risk (RR) and attributable fraction (AF) estimates of lung cancer (LC) and cardiopulmonary disease (CPD) mortality due to urban $PM_{2.5}$ pollution as presented in the 2000 global burden of disease (GBD) assessment for urban air pollution compared to re-calculated AF estimates in the current work

WHO Subregion	**2000 GBD Assessment for Urban Air Pollution**[a]		**Re-calculation: AF of LC Mortality Due to Urban $PM_{2.5}$**[b] **(%)**	**2000 GBD Assessment for Urban Air Pollution**[a]		**Re-calculation:AF of CPD Mortality Due to Urban $PM_{2.5}$**[b] **(%)**
	Relative Risk of LC	AF of LC Mortality Due to Urban $PM_{2.5}$ (%)		Relative Risk of CPD	AF of CPD Mortality Due to Urban $PM_{2.5}$ (%)	
AFR-D	1.210	5	17.4	1.148	2	12.9
AFR-E	1.100	2	9.1	1.071	1	6.6
AMR-A	1.040	3	3.8	1.029	2	2.8
AMR-B	1.093	4	8.5	1.066	3	6.2
AMR-D	1.153	6	13.3	1.108	3	9.7
EMR-B	1.105	4	9.5	1.075	3	7.0
EMR-D	1.309	8	23.6	1.214	4	17.6
EUR-A	1.044	2	4.2	1.032	1	3.1
EUR-B	1.138	5	12.1	1.098	3	8.9
EUR-C	1.065	3	6.1	1.046	2	4.4
SEAR-B	1.363	6	26.6	1.250	4	20.0
SEAR-D	1.272	4	21.4	1.190	3	16.0
WPR-A	1.071	4	6.6	1.051	3	4.9
WPR-B	1.311	10	23.7	1.216	6	17.8
World		**5**	**13.3**		**3**	**9.8**

[a] RR and AF estimates for CPD and LC are presented in Tables 17.9a and 17.9b respectively(80)

[b] AFs were re-calculated using *Equation 3*: $AF = \frac{RR_{X-X_0} - 1}{RR_{X-X_0}}$

Replication of subregional attributable fractions (AF_S) was eventually accomplished using the following equation based on *Equation 2b*:

$$AF_S = \frac{(P_U * RR_U + P_{NU} * RR_{NU} - 1)}{(P_U * RR_U + P_{NU} * RR_{NU})} \qquad \textit{(Equation 6a)}$$

where:

- RR_U and is the subregional relative risk of mortality due to urban air pollution in the urban population;
- RR_{NU} and is the subregional relative risk of mortality due to urban air pollution in the non-urban population;
- P_U is the subregional proportion of the urban population; and,
- P_{NU} is the subregional proportion of the non-urban population.

However, the specific association between urban air pollution and mortality in non-urban populations has not been the basis of any epidemiological studies, and therefore the RR_{NU} variable in *Equation 6a* does not exist. Thus, RR_{NU} was assumed to be 1.00, such that *Equation 6a* simplifies to:

$$AF_S = \frac{(P_U * RR_U + P_{NU} - 1)}{(P_U * RR_U + P_{NU})} \qquad \textit{(Equation 6b)}$$

Briefly, since it is unlikely that the non-urban population has zero increased risk of mortality due $PM_{2.5}$ originating from urban areas, assigning this population a relative risk of 1.00 likely underestimated the true global AF of mortality due to urban $PM_{2.5}$ pollution. Evidence supporting the use of *Equation 6b* in the WHO GBD for urban air pollution will be provided in the following discussion.

Tables 7.2 and 7.3 show the re-calculations of the attributable fractions of lung cancer and cardiopulmonary mortality associated with $PM_{2.5}$ exposure. The 2000 subregional urban populations were presented in the previous GBD for urban air pollution. The total 2000 subregional populations were obtained from the 2000 WHO GBD, version 3.(94) World AFs are the mean of subregional AFs.

Table 7.2 Re-calculation of the attributable fraction (AF) of lung cancer (LC) mortality due to urban $PM_{2.5}$ exposure as presented in the 2000 GBD for urban air pollution

WHO Subregion	**2000 GBD Assessment for Urban Air Pollution**[a]		**Re-calculation of the AF of LC Mortality due to $PM_{2.5}$ Exposure**				
	Relative Risk of LC Associated with $PM_{2.5}$	AF of LC Mortality (%)	2000 Urban Population (millions)[b]	Total 2000 Population (millions)[c]	Proportion of 2000 Population that is Urban (P_U)	Proportion of 2000 Population that is not Urban (P_{NU})	AF of Lung Cancer Mortality[d]
AFR-D	1.210	**5**	67	296	0.23	0.77	**5**
AFR-E	1.100	**2**	68	346	0.20	0.80	**2**
AMR-A	1.040	**3**	232	327	0.71	0.29	**3**
AMR-B	1.093	**4**	217	433	0.50	0.50	**4**
AMR-D	1.153	**6**	30	71	0.41	0.59	**6**
EMR-B	1.105	**4**	57	137	0.41	0.59	**4**
EMR-D	1.309	**8**	99	343	0.29	0.71	**8**
EUR-A	1.044	**2**	162	413	0.39	0.61	**2**
EUR-B	1.138	**5**	82	220	0.37	0.63	**5**
EUR-C	1.065	**3**	109	243	0.45	0.55	**3**
SEAR-B	1.363	**6**	54	291	0.18	0.82	**6**
SEAR-D	1.272	**4**	214	1,250	0.17	0.83	**4**
WPR-A	1.071	**4**	100	154	0.65	0.35	**4**
WPR-B	1.311	**10**	528	1,530	0.34	0.66	**10**
World[e]		**5**	**2,020**	**6,060**			**5**

[a] Relative risk estimates and attributable fractions for lung cancer are presented in Table 17.9b(80)

[b] 2000 urban populations were presented by subregion in Table 17.2(80)

[c] Total 2000 populations by subregion are presented in the 2000 GBD(94)

[d] AFs were calculated using *Equation 6b*: $AF_S = \frac{(P_U * RR_U + P_{NU} - 1)}{(P_U * RR_U + P_{NU})}$

[e] World AFs are the mean of subregional AFs

Table 7.3 Re-calculation of the attributable fraction (AF) of cardiopulmonary disease (CPD) mortality due to urban $PM_{2.5}$ exposure as presented in the 2000 GBD for urban air pollution

	2000 GBD Assessment for Urban Air Pollution[a]		**Re-calculation of the AF of CPD Mortality due to $PM_{2.5}$ Exposure**				
WHO Subregion	Relative Risk of CPD Mortality Associated with $PM_{2.5}$	AF of CPD Mortality (%)	2000 Urban Population (millions)[b]	Total 2000 Population (millions)[c]	Proportion of 2000 Population that is Urban (P_U)	Proportion of 2000 Population that is not Urban (P_{NU})	AF of CPD Mortality[d] (%)
AFR-D	1.148	**2**	67	296	0.23	0.77	**3**
AFR-E	1.071	**1**	68	346	0.20	0.80	**1**
AMR-A	1.029	**2**	232	327	0.71	0.29	**2**
AMR-B	1.066	**3**	217	433	0.50	0.50	**3**
AMR-D	1.108	**3**	30	71	0.41	0.59	**4**
EMR-B	1.075	**3**	57	137	0.41	0.59	**3**
EMR-D	1.214	**4**	99	343	0.29	0.71	**6**
EUR-A	1.032	**1**	162	413	0.39	0.61	**1**
EUR-B	1.098	**3**	82	220	0.37	0.63	**4**
EUR-C	1.046	**2**	109	243	0.45	0.55	**2**
SEAR-B	1.250	**4**	54	291	0.18	0.82	**4**
SEAR-D	1.190	**3**	214	1,250	0.17	0.83	**3**
WPR-A	1.051	**3**	100	154	0.65	0.35	**3**
WPR-B	1.216	**6**	528	1,530	0.34	0.66	**7**
World[e]		**3**	**2,020**	**6,060**			**3**

[a] Relative risk estimates and attributable fractions for lung cancer are presented in Table 17.9a(80)

[b] 2000 urban populations were presented by subregion in Table 17.2(80)

[c] Total 2000 populations by subregion are presented in the 2000 GBD, version 3(94)

[d] AFs were calculated using *Equation 6b*: $AF_S = \frac{(P_U * RR_U + P_{NU} - 1)}{(P_U * RR_U + P_{NU})}$; highlighted values indicate a discrepancy

[e] World AFs are the mean of subregional AFs

Attributable fractions for lung cancer mortality were reproduced exactly for all 14 subregions using *Equation 6b,* providing strong evidence that this methodology was used by the previous GBD for urban air pollution. Attributable fractions for cardiopulmonary disease mortality were exactly reproduced for 9 of the 14 subregions, and recalculation gave the same overall global AF for this air pollution cause of mortality. Of the 5 subregions where the AFs could not be exactly replicated, 4 were off by 1% when re-calculated using *Equation 6b* (AFR-D, AMR-D, EUR-B, WPR-B), and 1 was off by 2% (EMR-D). These differences are suspected to be due to choice of the population used when determining urban and non-urban proportions. The AF re-calculation employed subregional proportions of urban and non-urban populations based on all ages; and, while the previous GBD for urban air pollution estimated the burden of mortality from lung cancer in all ages, the burden of mortality from cardiopulmonary causes was assessed in adults only.(80) Unfortunately, calculating the urban and non-urban proportions in adult populations was not possible since the previous GBD for urban air pollution only provided subregional urban populations for all ages. The subregions previously outlined to have different AFs for cardiopulmonary disease mortality in the re-calculation scheme are also those suspected of having different proportions of urban and non-urban populations among adults versus all ages.

Rounding could be another possible explanation for the slight discrepancies seen in the re-calculation of cardiopulmonary disease mortality AFs compared to the original 2000 estimates. While this study used relative risks as they were presented in the 2000 GBD for urban air pollution (i.e. with three decimal places), to calculate the attributable fraction, the previous study may have used RRs with more or less decimal places to calculate the AFs. It was found that rounding the RRs from 3 to 2 decimal places altered the AFs in most instances, indicating that *Equation 6b* is sensitive to small changes in the RR. Similarly, differences in rounding of the proportions of urban and non-urban could explain differences in results.

A final source of the small discrepancies seen in the re-calculation of cardiopulmonary disease mortality AFs could be related to the version of the 2000 WHO GBD used to determine the total suberegional populations. The only version available online by subregion (as opposed to region) was version 3, which provided estimates for 2000 consistent with the estimates for 2002 reported in the World Health Report (WHR) 2003. Version 1 provided estimates for 2000 as presented in the 2001 WHR, and version 2 provided estimates for 2000 consistent with the estimates for 2001 as reported in the 2002 WHR. It is not clear which version was used in 2000 GBD on urban air pollution. Overall, the similarities between the AFs presented in the WHO GBD for urban air pollution and those re-calculated using *Equation 6b* provides strong evidence supporting use of this methodology in the WHO's work.

The method used to derive AFs in this thesis differs slightly from the methodology that was assumed to have been used in the previous GBD for urban air pollution. First, this thesis is interested assessing mortality attributable to global levels of $PM_{2.5}$ pollution and not just that originating from urban sources. Second, by using global satellite imagery, the current work did not have to distinguish between urban and rural populations since population weighted $PM_{2.5}$ exposures were available such that mean exposure levels were representative of both groups.

7.4 Comparison with the 2000 GBD for Urban Air Pollution

7.4.1 Ambient $PM_{2.5}$ Concentrations

In the 2000 GBD for urban air pollution, ambient PM_{10} concentrations were derived for all worldwide cities with populations >100,000 as well as national capitals, using the Global Model of Ambient Particulates (GMAPS) developed by the World Bank.(80) GMAPS is based on available measurements of PM_{10} and total suspended particles (TSP) at population-oriented monitoring sites (i.e. urban sites), and incorporates information on such factors as fuel mix, level of economic development, demographics, and weather. In total, PM_{10} and TSP data existed from 512 locations for 304 cities in 55 countries over the period of 1985-1999, yielding 2344 unique observations. The 304 cities accounted for 9% of the total number of cities with population >100,000 and 28% of the global *urban* population.

The $PM_{2.5}$ concentrations used in this thesis were found to have good correlation with ground-level measurements in North America and elsewhere.(82) In comparison with the 2000 GBD for urban air pollution, the global satellite derived $PM_{2.5}$ estimates employed in the current study had better population coverage, representing 98% of the global population.

In general, the satellite derived estimates of subregional fine particulate matter concentrations were lower than those presented in the 2000 GBD, with only EMR-B, EUR-A, and WPR-B subregions having higher satellite values. As was shown in section 6.1.3, the differences in the mean subregional $PM_{2.5}$ concentrations between the studies are explained in part by low correlations between predicted PM_{10} estimates and observed PM_{10} estimates in the 2000 GBD. Primarily, however, the mean subregional $PM_{2.5}$ estimates of the current study were lower since they were not focused solely on urban aerosol pollution, but on $PM_{2.5}$ concentrations for urban and rural regions.

7.4.2 Fractions of Mortality Attributable to $PM_{2.5}$

The attributable fractions of mortality derived in this thesis were larger than those derived in the previous GBD. One source for the observed disagreements was that the exposures of interest were different between the studies. In comparison with the 2000 GBD for urban air pollution, this thesis considered mortality attributable to global $PM_{2.5}$ pollution, and not just that originating from urban sources; and, through use of satellite imagery, this work did not have to consider rural populations as unexposed to urban $PM_{2.5}$ pollution.

The other main factors leading to the higher attributable fractions noted in this thesis compared to the 2000 GBD for urban air pollution were the use of larger risk coefficients for the association between $PM_{2.5}$ and mortality, as well as a smaller theoretical minimum value. The use of a more sophisticated model, a Cox Random Effects survival model with 1 level of clustering and adjustment for 7 ecological covariates, generally increased the $PM_{2.5}$ hazard ratios (HRs) for all-cause, cardiovascular, lung cancer, and ischemic heart disease mortalities. Furthermore, accounting for random effects increased not only the air pollution risk estimate but also inflated uncertainty in the estimates compared with the standard Cox model. While both works employed the lowest observed $PM_{2.5}$ concentration used to derive the risk coefficients, the 2000 GBD used a reference value of $7.5\mu g/m^3$ based on the 1979-1983 exposure data collection period, while the current work employed the lowest observed concentration from the 1999-2000 $PM_{2.5}$ data collection period, $5.8\mu g/m^3$. As was observed in this work, lower reference concentrations were associated with increased risk estimates.

When the risk coefficients, theoretical-minimum reference value, and maximum exposure threshold from the base case assessment of the 2000 GBD for urban air pollution were applied to the current analysis, the attributable fractions for lung cancer and cardiopulmonary disease decreased by roughly half. Using lower risk coefficients, a reference value of $7.5\mu g/m^3$, and maximizing risk at $50\mu g/m^3$ produced attributable fractions of 4.4% and 6.2%

for cardiopulmonary disease and lung cancer respectively, which were not significantly different for estimates derived in the previous GBD for urban air pollution, 3% (1-6) and 5% (1-9) for cardiopulmonary disease and lung cancer respectively. While risk was maximized at 50μg/m^3 in order to be consistent with the methods used in the previous GBD for urban air pollution, this factor alone did not change the global attributable fraction estimates since WPR-B was the only subregion with country pollution data above this value. Had mean satellite-derived $PM_{2.5}$ exposure data been available for the urban regions within each the countries, the comparison would have additionally restricted to derive AFs for urban $PM_{2.5}$ pollution while assigning a relative of 1.00 to rural populations. It is expected that the resulting AFs of such an assessment would have been smaller than are presented here.

The primary factors leading to differences between this study and the 2000 GBD for urban air pollution are related to the risk coefficients and reference value used, such that when those differences are removed, the attributable fractions produced using the exposure data and methodology of this thesis are not significantly different from those produced in the previous GDB for urban air pollution.

7.5 Study Strengths

7.5.1 Satellite-Derived Ambient $PM_{2.5}$ Concentrations

As previously discussed, the $PM_{2.5}$ concentrations employed in this thesis were obtained from two different satellite instruments, MISR and MODIS, via methodology which optimized the strengths of each device while minimizing limitations. It is generally acknowledged that combining measures from different sensors can reduce the uncertainty in column retrievals and ultimately $PM_{2.5}$ estimates.(39) Global $PM_{2.5}$ estimates represented 98% of the global population, and were found to have good correlation with ground-level measurements in North America and elsewhere.(82)

7.5.2 Risk Coefficients

Spatial autocorrelation due to the complex spatial patterns in the ACS data have been observed.(64) The Cox survival model assumes independence of individual survival times over space and time, an assumption that is not met if survival clusters at the ecological level. If similarities in longevity vary by geo-space, even after controlling for the appropriate risk factors, risk estimates and their variances could be biased. In order to account for these spatial patterns, one must consider using a random effects survival model. Instead of giving equal weight to all subjects' information as does the standard Cox model, the random effects model weights the information by cluster. The weight given to a cluster depends on its variance, and larger clusters are given less weight compared to their sample size in the random effects model compared to the standard Cox model. The current study employed risk coefficients derived from a random effects survival model.

7.6 Study Limitations

7.6.1 Use of ACS Cohort to Develop Risk Coefficients

Risk coefficients were derived from the largest and most studied cohort on air pollution and long-term mortality to date, with enrolment of 1.2 million adult participants in 1982 which were followed-up for 18 years until the end of 2000. Several limitations of this study are related to the use of the ACS cohort to develop risk coefficients for the association between $PM_{2.5}$ and mortality.

The ACS cohort enrolled individuals aged 30 years or older, who were predominantly white (94%), and had at least a high school education (89%).(64) By generalizing the risk coefficients derived in the ACS cohort to the global population, including developing countries which have different demographics and potentially different susceptibilities to the effects of air pollution, uncertainty and potentially bias were introduced into the analysis. Vulnerability to PM exposure is thought to vary by socioeconomic status (SES) factors as well as by risk behaviours such as smoking. For instance, education was shown to modify the effects of long-term PM exposure on mortality in the ACS cohort, such that individuals with lower educational attainment had higher risks of mortality.(62-64) This modifying effect is not necessarily thought to be attributable to education per se, but rather that education is a marker for a complex set of SES factors that have an impact on risk.(64)

The APHENA study, a collaborative analysis of multicity time-series data on the effect of air pollution on population health in Europe and Northa America, also reported effect modification by SES-related variables and age on the association between acute PM exposure and mortality. In both Europe and the United States, populations with a higher proportion of older people as well as higher rates of unemployment were associated with increased risk of mortality due to *acute* PM exposure.(95) Climatic variables were also shown to have a modifying effect in Europe where higher temperature and lower humidity were associated with larger PM_{10} effects; however, no effect modification was observed for climatic variables in the U.S(95), and effect modification by climatic factors has not been reported in cohort studies of long-term PM exposure and mortality.

Although it is somewhat reassuring that several researchers have demonstrated that the relationship between acute PM exposure and mortality remains relatively consistent across various countries and continents (95-97), if the effects of long-term PM exposure on mortality are more severe among populations with lower measures of SES-related factors, it would be expected this work underestimated the magnitude of burden since a large portion of the world's population lives below poverty line. Currently, longitudinal cohort studies on PM exposure and mortality in developing countries are lacking, and research is required in this area to better characterize global burden attributable to long-term PM exposure.

Another limitation of the parameter estimates for the association between $PM_{2.5}$ and mortality was related to the temporality of mortality and $PM_{2.5}$ data collection. While mortality was collected over a 16-year period, two periods of air pollution data collection existed, one at the beginning of the study, 1979-1983, and one at the end of follow-up, 1999-2000. The current assessment employed linear and log-linear risk coefficients based on pollution exposure data from 1999-2000 since they were derived using ecological covariate adjustment. However, the majority of mortality modelled occurred prior to the collection of exposure levels. Mean $PM_{2.5}$ concentrations decreased from 21.2μg/m^3 in the 1979-1983 collection period to 14.0μg/m^3 in the 1999-2000 collection period as a result of more stringent air pollution standards.(63) Temporally, chronic exposure to $PM_{2.5}$ which contributed to the physiological progression of disease leading to all cause, cardiovascular, lung cancer of ischemic heart disease mortality likely occurred closer to the first collection period as opposed to the second collection period, which occurred at the end of follow-up. As a result of mortality risk coefficients being derived from exposure levels that were lower than those actually associated with mortality, risk estimates were likely overestimated, as is evidenced by risk coefficients being higher based on exposure levels obtained from the first collection period versus the second collection period.(63) However, it was thought to be most important to employ risk coefficients which were adjusted for ecological covariates in order to account for socio-demographic risks and decrease overall bias in the estimates.

Despite these aforementioned limitations of the risk coefficients, it is widely accepted that the parameter estimates derived from the ACS study are the best available for use in assessing mortality due to long-term exposure to fine particulate matter.

7.6.2 Study Design

Aspects of the study design resembled an ecological study where the unit of study was the population, and individual exposure levels could not be ascertained. Risk coefficients for the associations between $PM_{2.5}$ exposure and four causes of mortality were based on the ACS study which prospectively followed-up on mortality at the individual level, but where exposure was derived at the population level and was assumed to be the same for all individuals. The subregional attributable fractions derived in this thesis were based on these risk coefficients, as well as cross sectional mortality and $PM_{2.5}$ concentration data where the unit of analysis was also at the population level, and exposure levels were assumed to be the same for all individuals. By population weighting the $PM_{2.5}$ estimates, mean country-level $PM_{2.5}$ concentrations better represented all individuals in the population.

7.6.3 Mortality Data

The country-level mortality data used to calculate the attributable fraction of mortality only existed for 57% of the countries with $PM_{2.5}$ values, which resulted in a loss of $PM_{2.5}$ data; and, although country-level mortality estimates derived in this thesis from the WHO mortality database were adjusted for low coverage, comparisons for all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease revealed that world mortality estimates represented only 34%, 39%, 56%, and 48% of the number of deaths estimated in modelling activities in the WHO GBD 2004 update.(90) The differences in numbers of deaths calculated in this study versus in the WHO GBD 2004 update varied by subregion. These difference were small or negligible for subregions AMR-A/B, EUR-A/C, and WPR-A, and were largest for subregions AFR-D and SEAR-D. The primary sources for the discrepancies in subregional mortality estimates were due to the WHO GBD estimates being the result of modelling activities, versus this thesis which extracted raw mortality counts at the country level. Furthermore, the 2004 WHO GBD was based on data for 192 member states, while this thesis only extracted data for 132 countries.

In addition to the complete lack of mortality data for over 40% of the regions with $PM_{2.5}$ data, there were many countries that had poor quality mortality data. A few countries reported mortality using ICD-7 and ICD-8 coding. Mortality for Taiwan was reported using ICD-7 and mortality for Cape Verde, Iran, and Turkey was reported using ICD-8. These versions of disease classification are much less detailed than ICD-9 or ICD-10 coding. Also, 17 countries had mortality data that was $\geq$10 years older than the year of the population data used to weight the $PM_{2.5}$ exposures, 2005. Mortality has changed over the last decade, and varies for each country by cause of mortality in relation to its population growth rate and age distribution of the population.

The impact of using ICD-10 coding in this analysis compared with other previous similar analysis which employed ICD-9 coding is not expected to impact the results since it has previously been shown that the change from ICD-9 to ICD-10 coding did not significantly affect the estimated effects of air pollution on mortality.(98)

The low quality or lack of mortality data for countries that do not have well established public health surveillance programs was a limitation of this work.

7.6.4 Uncertainty

The statistical uncertainty presented in this thesis for the relative risk and attributable fraction estimates is related to the uncertainty in the parameter estimates for the association between $PM_{2.5}$ and mortality. One limitation of quantifying statistical uncertainty in this work was due to the unavailability of systematic uncertainty related to mean country-level $PM_{2.5}$ concentrations. In a recent review of the literature, it has been estimated that the precision in measuring AOD is ±20%, and that its relationship to $PM_{2.5}$ is at best ±30% in controlled measurements (i.e. aerosol type, boundary layer structure are known).(39) Had this information on exposure error been available, this thesis would have further quantified statistical uncertainty of relative risks and attributable fractions by estimating the combined uncertainty of the mean $PM_{2.5}$ concentrations and of the risk coefficients associated with $PM_{2.5}$. Incorporating uncertainty of satellite measurements would have increased the overall uncertainty of all estimates presented in this work.

Model uncertainty due assumptions about the shape of the concentration-response function, theoretical-minimum exposure, and maximum exposure threshold were assessed in the sensitivity analyses.

Another source of uncertainty in this work is the sampling variation in the concentration-response estimates from the ACS compared to other studies, which can be represented by the variation in risk estimates among cohort studies assessing mortality and PM.(10,60,80) A final source of uncertainty is associated with the country-level mortality rate estimates. Overall, this work is associated with high levels of uncertainty which cannot completely be quantified.

7.7 Recommendations

7.7.1 Best Estimate of Fractions of Mortality Attributable to $PM_{2.5}$

As was outlined in earlier discussion sections, the best estimate of the fractions of mortality attributable to fine particulate matter is for the anthropogenic component under the base case scenario.

7.7.2 All Cause Mortality

The distribution of all causes of mortality varies substantially throughout the world, and the risk coefficients for the association between mortality and $PM_{2.5}$ are based on a cohort from the U.S. population, which is not representative of the demographics elsewhere in the world. In order to assess the impact of assessing global all cause mortality due to $PM_{2.5}$, the stability of the relationship between cardiopulmonary deaths and all other causes of mortality was determined at the country level. While the risk of all cause mortality due to $PM_{2.5}$ was found to be significant in the U.S., this association may primarily be the result of the association between cardiopulmonary disease mortality and $PM_{2.5}$, a large cause of mortality in the U.S. population. Since the proportion of all cause mortality that is due to cardiopulmonary disease was the same (i.e., proportions were within a 10 percent range across the age categories) for only 25% of the countries assessed, it is recommended that the attributable fractions of all cause mortality due to $PM_{2.5}$ only be discussed for those subregions with similar proportions, and not at a global level.

7.7.3 Future Work

The methods used in this thesis to derive attributable fractions of mortality associated with $PM_{2.5}$ were relatively crude, and future work should be undertaken to refine these methodologies. One key area to develop would be the derivation of $PM_{2.5}$ estimates. Despite the improvements in remote sensory technology over the past decade, there is still a need for greater precision in satellite measures.(39) As such, sources for $PM_{2.5}$ concentration estimates could be combined, including ground-level monitors, satellite imagery, and modelling activities to supplement areas with poor satellite coverage, such as Africa.

Another important area to focus future activities on would be the development of age and sex specific risk coefficients for the association between $PM_{2.5}$ and mortality so that attributable fractions can be stratified by age and sex as is described in the generic methodology chapters for WHO GBD assessments.

Finally, more complex concentration-response functions, such as a linear-log-linear hybrid model could be developed to model risk of mortality associated with chronic $PM_{2.5}$ exposure. Initially it was thought that a hybrid linear and log-linear function would be an interesting way to model risk such that the linear model would be used to characterize risk up until it intersects with the log-linear model, after which point the log-linear model would used to further characterize risk. This model was thought to avoid overestimating risk at lower and higher concentrations when using the log-linear and linear functions respectively. Figure 7.1 shows linear – log-linear hybrid models for all four causes of mortality under hypothetical exposure ranges.

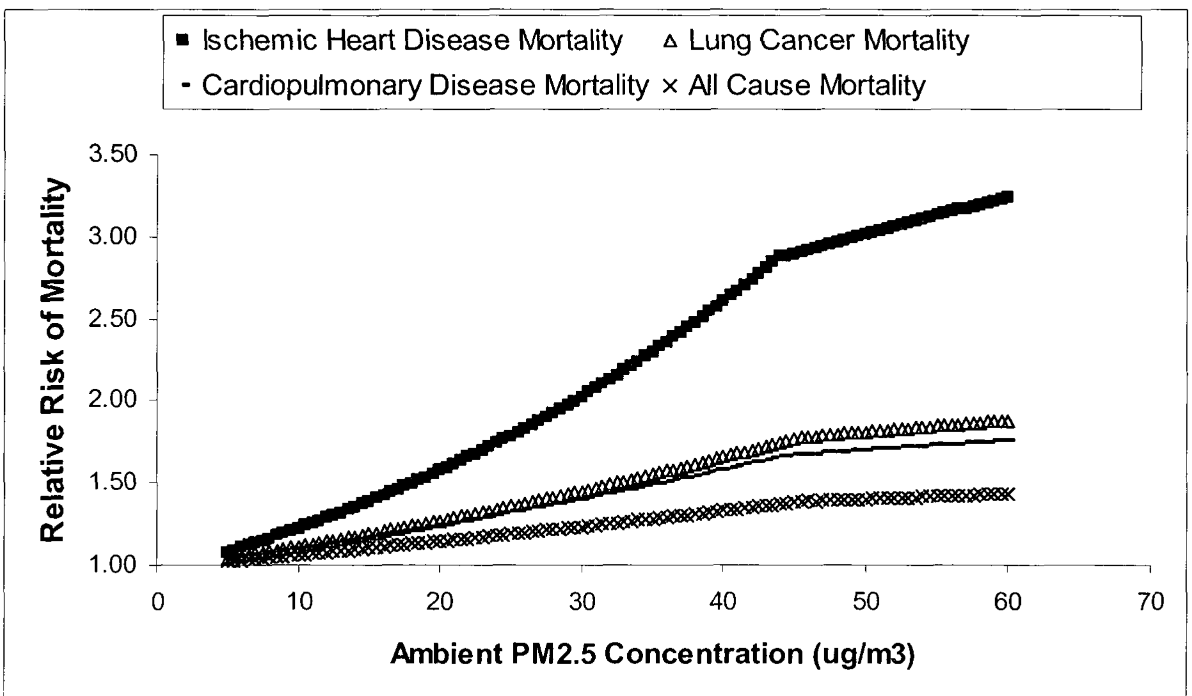

Figure 7.1 Hypothetical linear – log-linear hybrid models for all four air pollution causes of mortality

While the model appears to be a reasonable way to characterize risk, use of this complex function introduces some mathematical issues beyond the scope of this thesis, and therefore was not included in the current work.

7.8 Conclusion

Use of satellite derived air pollution measures in epidemiological studies is a new area of research, and previous cross-sectional and longitudinal studies of air pollution and health have traditionally relied on ground-level monitors, typically situated in urban areas. Techniques for deriving $PM_{2.5}$ from remote sensing data have been evolving quickly, and satellite imagery technology is now at a stage where concentrations for several major pollutants, and specifically fine particulate matter, can be determined with a certain degree of accuracy. (56,57) This technology has the potential of becoming a primary measure of air pollution as it poses the advantage of global coverage. Differences in the attributable fractions of mortality associated with $PM_{2.5}$ derived in this study compared to the 2000 GBD for urban air pollution were explained, and were not found to be the result of different tools used to measure $PM_{2.5}$ – modelling versus satellite imagery. This study demonstrated that it is feasible to use satellite derived pollution concentrations in the global assessment of mortality.

REFERENCES

(1) Ostro B. Outdoor air pollution: Assessing environmental burden of disease at national and local levels. World Health Organization, Geneva, 2004.

(2) Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, et al. An association between air pollution and mortality in six U.S. cities. N. Engl. J. Med. 1993;329(24):1753.

(3) World Health Organization. Health aspects of air pollution. Results from the WHO project Systematic Review of Health Aspects of Air Pollution in Europe. 2004;E83080.

(4) Miller FJ, Gardner DE, Graham JA, Lee REJ, Wilson WE, Bachmann JD. Size considerations for establishing a standard for inhalable particles. J. Air Poll. Control Assoc. 1979;29:610.

(5) Pope CA, Verrier RL, Lovett EG, Larson AC, Raizenne ME, Kanner RE, et al. Heart rate variability associated with particulate air pollution. Am. Heart. J. 1999;138(5):890.

(6) Williams ML. Air quality risk management. J. Toxicol. Environ. Health A. 2008;71(1):9.

(7) Jerrett M, Burnett RT, Ma R, Pope CA, Krewksi D, Newbold KB, et al. Spatial analysis of air pollution and mortality in Los Angeles. Epidemiology 2005;16(6):727.

(8) Pope CA, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE, et al. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. Am. J. Respir. Crit. Care Med. 1995;151(3):669.

(9) Pope CA, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, et al. Lung cancer, cariopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 2002;287(9):1132.

(10) Cohen AJ, Anderson HR, Ostro B, Pandey KD, Krzyzanowski M, Kunzli N, et al. The global burden of disease due to outdoor air pollution. J. Toxicol. Environ. Health A. 2005;68(13-14):1301.

(11) Liu Y, Sarnat JA, Kilaru V, Jacob DJ, Koutrakis P. Estimating ground-level PM2.5 in the Eastern United States using satellite remote sensing. Environ. Sci. Technol. 2005;39(9):3269.

(12) Martin RV. Satellite remote sensing of surface air quality. Atmos. Environ. 2008;42(34):7823.

(13) Chu DA, Kaufman YJ, Zibordi G, Chern JD, Mao J, Li C, et al. Global monitoring of air pollution over land from the Earth Observing System-Terra Moderate Resolution Imaging Spectroradiometer (MODIS). J. Geophys. Res. 2003;108(D21):4661.

(14) Akimoto H. Global air quality and pollution. Science 2003;302(5651):1716.

(15) Gupta P, Sundar AC, Wang J, Gehrig R, Lee Y, Kumar N. Satellite remote sensing of particulate matter and air quality assessment over global cities. Atmos. Environ. 2006;40(30):5880.

(16) Engel-Cox JA, Hoff RM, Haymet ADJ. Recommendations on the use of satellite remote-sensing data for urban air quality. J. Air Waste Manag. Assoc. 2004;54(11):1360.

(17) Edwards DP, Lamarque J-, Attié J-, Emmons LK, Richter A, Cammas J-, et al. Tropospheric ozone over the tropical Atlantic: A satellite perspective. J. Geophys. Res. 2003;108(D8):4237.

(18) King MD, Kaufman YJ, Tanré D, Nakajima T. Remote sensing of tropospheric aerosols from space: Past, present, and future. Bul.Am.Met.Soc. 1999;80(11):2229.

(19) Engel-Cox JA, Young GS, Hoff RM. Application of satellite remote-sensing data for source analysis of fine particulate matter transport events. J.Air Waste Manag.Assoc. 2005 Sep;55(9):1389-1397.

(20) Kaufman YJ, Tanré D, Boucher O. A satellite view of aerosols in the climate system. Nature 2002;419(6903):215.

(21) Remer LA, Tanré D, Kaufman YJ, Ichoku C, Mattoo S, Levy R, et al. Validation of MODIS aerosol retrieval over ocean. Geophys. Res. Let. 2002;29(12):1618.

(22) Martonchik JV, Diner DJ, Kahn RA, Ackerman TP, Verstraete MM, Pinty B, et al. Techniques for the retrieval of aerosol properties over land and ocean using multiangle imaging. IEEE Trans. Geosci. Remote Sens. 1998;36(4):1212.

(23) Koelemeijer RBA, Homan CD, Matthijsen J. Comparison of spatial and temporal variations of aerosol optical thickness and particulate matter over Europe. Atmos. Environ. 2006;40(27):5304.

(24) Al-Saadi J, Szykman J, Pierce RB, Kittaka C, Neil D, Chu DA, et al. Improving national air quality forecasts with satellite aerosol observations. Bul.Am.Met.Soc. 2005;86(9):1249.

(25) Chu DA, Kaufman YJ, Ichoku C, Remer LA, Tanré D, Holben BN. Validation of MODIS aerosol optical depth retrieval over land. Geophys. Res. Let. 2002;29(12):1617.

(26) Ichoku C, Remer LA, Eck TF. Quantitative evaluation and intercomparison of morning and afternoon Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol measurements from Terra and Aqua. J. Geophys. Res. 2005;110(D10S03):1.

(27) Kim S-, Yoon S-, Kim J, Kim S-. Seasonal and monthly variations of columnar aerosol optical properties over east Asia determined from multi-year MODIS, LIDAR, and AERONET Sun/sky radiometer measurements. Atmos. Environ. 2007;41(8):1634.

(28) Kaufman YJ, Tanré D, Remer LA, Vermote EF, Chu A, Holben BN. Operational remote sensing of tropospheric aerosol over land from EOS moderate resolution imaging spectroradiometer. J Geophys. Res. 1997;102(D14):17051.

(29) Tanré D, Kaufman YJ, Herman M, Mattoo S. Remote sensing of aerosol properties over oceans using the MODIS/EOS spectral radiances. J Geophys. Res. 1997;102(D14):16971.

(30) Hutchison KD, Faruqui SJ, Smith S. Improving correlations between MODIS aerosol optical thickness and ground-based PM2.5 observations through 3D spatial analyses. Atmos. Environ. 2008;42(3):530.

(31) Hutchison KD, Smith S, Faruqui SJ. Correlating MODIS aerosol optical thickness data with ground-based PM2.5 observations across Texas for use in a real-time air quality prediction system. Atmos. Environ. 2005;39(37):7190.

(32) Levy RC, Remer LA, Martins JV, Kaufman YJ, Plana-Fattori A, Redemann J, et al. Evaluation of the MODIS aerosol retrievals over ocean and land during CLAMS. J. Atmos. Sci. 2005;62(4):974.

(33) Jiang X, Liu Y, Yu B, Jiang M. Comparison of MISR aerosol optical thickness with AERONET measurements in Beijing metropolitan area. Rem. Sens. Environ. 2007;107(1-2):45.

(34) Diner DJ, Beckert JC, Reilly TH, Bruegge CJ, Conel JE, Kahn RA, et al. Multi-angle Imaging SpectroRadiometer (MISR) intrument description and experiment overview. IEEE Trans. Geosci. Remote Sens. 1998;36(4):1072.

(35) Abdou WA, Diner DJ, Martonchik JV, Bruegge CJ, Kahn RA, Gaitley BJ, et al. Comparison of coincident Multiangle Imaging Spectroradiometer and Moderate Resolution Imaging Spectroradiometer aerosol optical depths over land and ocean scenes containing Aerosol Robotic Network sites. J. Geophys. Res. 2005;110(D10S07):1.

(36) Xiao N, Shi T, Calder CA, Munroe DK, Berrett C, Wolfinbarger S, et al. Spatial characteristics of the difference between MISR and MODIS aerosol optical depth retrievals over mainland Southeast Asia. Rem. Sens. Environ. 2009;113(1):1.

(37) Prasad AK, Singh RP. Comparison of MISR-MODIS aerosol optical depth over the Indo-Gangetic basin during the winter and summer seasons (2000-2005). Rem. Sens. Environ. 2007;107(1-2):109.

(38) Liu Y, Franklin M, Kahn R, Koutrakis P. Using aerosol optical thickness to predict ground-level PM2.5 concentrations in the St. Louise area: A comparison between MISR and MODIS. Rem. Sens. Environ. 2007;107(1-2):33.

(39) Hoff RM, Christopher SA. Remote sensing of particulate pollution from space: Have we reached the promised land? J. Air & Waste Manage. Assoc. 2009;59:645.

(40) Carbon emissions from spring 1998 fires in tropical Mexico. Joint Fire Conference and Workshop: Crossing the Millennium: Integrating Spatial Technologies and Ecological Principals for a New Age in Fire Management; 1999; : The University of Idaho; 1999.

(41) Falke SR, Husar RB, Schichtel BA. Fusion of SeaWiFS and TOMS satellite data with surface observations and topographic data during extreme aerosol events. J.Air Waste Manag.Assoc. 2001 Nov;51(11):1579-1585.

(42) Husar RB, Tratt DM, Schichtel BA, Falke SR, Li F, Jaffe D, et al. Asian dust events of April 1998. J. Geophys. Res. 2001;106(D16):317.

(43) Hutchison KD, Smith S, Faruqui S. The use of MODIS data and aerosol products for air quality prediction. Atmos. Environ. 2004;38(30):5057.

(44) van Donkelaar A, Martin RV, Leaitch WR, Macdonald AM, Walker TW, Streets DG, et al. Analysis of aircraft and satellite measurements from the Intercontinental Chemical Transport Experiment (INTEX-B) to quantify long-range transport of East Asian sulfur to Canada. Atmos. Chem. Phys. 2008;8(11):2999.

(45) Hu Z, Rao KR. Particulate air pollution and chronic ischemic heart disease in the eastern United States: a county level ecological study using satellite aerosol data. Environ.Health 2009 Jun 12;8:26.

(46) Hu Z. Spatial analysis of MODIS aerosol optical depth, PM2.5, and chronic coronary heart disease. Int.J.Health.Geogr. 2009 May 12;8:27.

(47) Holben BN, Eck TF, Slutsker I, Tanre D, Buis JP, Setzer A, et al. AERONET - A federated instrument network and data archive for aerosol characterization. Rem. Sens. Environ. 1998;66(1):1.

(48) Kahn RA, Gaitley BJ, Martonchik JV, Diner DJ, Crean KA. Multiple Imaging Spectroradiometer (MISR) global aerosol optical depth validation based on 2 years of coincident Aerosol Robotic Network (AERONET) observations. J. Geophys. Res. 2005;110(D10S04):1.

(49) Liu Y, Sarnat JA, Coull BA, Koutrakis P, Jacob DJ. Validation of Multiangle Imaging Spectroradiometer (MISR) aerosol optical thickness measurements using Aerosol Robotic Network (AERONET) observations over the contiguous United States. J. Geophys. Res. 2004;106(D06205):1.

(50) Christopher SA, Wang J. Intercomparison between multi-angle imaging spectroradiometer (MISR) and sunphotometer aerosol optical thickness in dust source regions over China: implications for satellite aerosol retrievals and radiative forcing calculations. Tellus B 2004;56(5):451.

(51) Martonchik JV, Diner DJ, Kahn R, Gaitley B. Comparison of MISR and AERONET aerosol optical depths over desert sites. Geophys. Res. Let. 2004;31(L16102):1.

(52) Hu R-, Sokhi RS, Fisher BEA. New algorithms and their application for satellite remote sensing of surface PM2.5 and aerosol absorption. Aeros. Sci. 2009;40(5):394.

(53) Engel-Cox JA, Holloman CH, Coutant BW, Hoff RM. Qualitative and quantitative evaluation of MODIS satellite sensor data for regional and urban scale air quality. Atmos. Environ. 2004;38(16):2495.

(54) Li H, Faruque F, Williams W, Al-Hamdan M, Luvall J, Crosson W, et al. Optimal temporal scale for the correlation of AOD and ground measurements of PM2.5 in a real-time air quality estimation system. Atmos. Environ. 2009;43(28):4303.

(55) Pelletier B, Santer R, Vidot J. Retrieving of particulate matter from optical measurements: A semiparametric approach. J. Geophys. Res. 2007;112(D06208):1.

(56) Liu Y, Park RJ, Jacob DJ, Li Q, Kilaru V, Sarnat JA. Mapping annual mean ground-level PM2.5 concentrations using Multiangle Imaging Spectroradiometer aerosol optical thickness over the contiguous United States. J. Geophys. Res. 2004;109(D22206):1.

(57) van Donkelaar A, Martin RV, Park RJ. Estimating ground-level PM2.5 using aerosol optical depth determined from satellite remote sensing. J. Geophys. Res. 2006;111(D21201):1.

(58) Gupta P, Christopher SA. An evaluation of Terra-MODIS sampling for monthly and annual particulate matter air quality assessment over the Southeastern United States. Atmos. Environ. 2008;42(26):6465.

(59) Gupta P, Christopher SA, Box MA, Box GP. Multi year satellite remote sensing of particulate matter air quality over Sydney, Australia. Int. J Rem. Sens. 2007;28(20):4483.

(60) U.S. EPA. Integrated science assessment for particulate matter (final report). Chapter 7. Integrated health effects of long-term PM exposure. 2009;EPA/600/R-08/139F.

(61) Laden F, Schwartz J, Speizer FE, Dockery DW. Reduction in fine particulate air pollution and mortality: extended follow-up of the Harvard Six Cities study. Am. J. Resp. Crit. Care Med. 2006;173:667.

(62) Pope CA, Burnett RT, Thurston GD, Thun MJ, Calle EE, Krewski D, et al. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. Circulation 2004;109:71.

(63) Krewski D, Jerrett M, Burnett RT, Ma R, Hughes E, Shi Y, et al. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. Res Rep Health Eff Inst 2009;140:5.

(64) Krewski D, Burnett R, Goldberg MS, Koover K, Siemiatycki J, Abrahamowicz M, et al. Reanalysis of the Havard six cities study and the American Cancer Society study of particulate air pollution and mortality. Res Rep Health Eff Inst 2000.

(65) McDonnell WF, Nishino-Ishikawa N, Petersen FF, Chen LH, Abbey DE. Relationships of mortality with the fine and coarse fractions of long-term ambient PM10 concentrations in nonsmokers. J Expo Sci Environ Epidemiol 2000;10:427.

(66) Chen LH, Knutsen SF, Shavlik D, Beeson WL, Petersen F, Ghamsary M, et al. The association between fatal coronary heart disease and ambient particulate air pollution: Are females at greater risk? Environ. Health Persp. 2005;113:1723.

(67) Lipfert FW, Wyzga RE, Baty JD, Miller JP. Traffic density as a surrogate measure of environmental exposures in studies of air pollution health effects: long-term mortality in a cohort of US veterans. Atmos. Environ. 2006;40:154.

(68) Miller KA, Siscovick DS, Sheppard L, Shepherd K, Sullivan JH, Anderson GL, et al. Long-term exposure to air pollution and incidence of cardiovascular events in women. N Engl J Med 2007;356:447.

(69) Puett RC, Schwartz J, Hart JE, Yanosky JD, Speizer FE, Suh H, et al. Chronic particulate exposure, mortality, and coronary heart disease in the nurses' health study. Am. J. Epidemiol. 2008;168:1161.

(70) Eftim SE, Samet JM, Janes H, McDermott A, Dominici F. Fine particulate matter and mortality: a comparison of the six cities and American Cancer Society cohorts with a medicare cohort. Epidemiology 2008;19:209.

(71) U.S. Environmental Protection Agency. U.S. EPA. Integrated Science Assessment for Particulate Matter (Second External Review Draft). 2009;EPA/600/R-08/139B.

(72) Zeger S, Dominici F, McDermott A, Samet J. Mortality in the Medicare population and chronic exposure to fine particulate air pollution in urban centers (2000-2005). Environ. Health Persp. 2008;116(12):1614.

(73) Brunekreef B, Beelen R, Hoek G, Schouten L, Bausch-Goldbohm S, Fischer P, et al. Effects of long-term exposure to traffic-related air pollution on respiratory and cardiovascular mortality in the Netherlands: The NLCS-AIR Study. 2009;139.

(74) Ostro B, Lipsett M, Reynolds P, Goldberg D, Hertz A, Garcia C, et al. Long-Term Exposure to Constituents of Fine Particulate Air Pollution and Mortality: Results from the California Teachers Study. Environ. Health Persp. 2010;118(3):363.

(75) Ezzati M, Lopez AD, Rodgers A, Hoorn SV, Murray CJL. Selected major risk factors and global and regional burden of disease. Lancet 2002;360:1347.

(76) Industrial Economics I. Expanded expert judgment assessment of the concentration-response relationship between PM2.5 exposure and mortality. 2006.

(77) Costa DL. Air Pollution. In: Klaassen CD, editor. Casarett and Doull's Toxicology. The basic science of poisons. 6th ed. Toronto: McGraw-Hill; 2001.

(78) Araujo JA, Nel AE. Review: Particulate matter and atherosclerosis: role of particle size, composition and oxidative stress. Part. Fibre Toxicol. 2009;6:24.

(79) U.S. EPA. Air quality criteria for particulate matter. 2004;EPA/600/P-99/002aF-bF.

(80) Cohen AJ, Anderson HR, Ostro B, Pandey KD, Krzyzanowski M, Kuenzli N, et al. Mortality impacts of urban air pollution. In Comparative quantification of health risks: Global and regional burden of disease due to selected major risk factors. 2004;2.

(81) Beaglehole R, Irwin A, Prentice T. Statistical annex. In The World Health Report 2004 - changing history. 2004:156.

(82) van Donkelaar A, Randall M, Brauer M, Kahn R, Levy R, Verduzco C, et al. Global estimates of exposure to fine particulate matter concentrations from satellite-based aerosol optical depth. Environ. Health Persp. In Press;In Press.

(83) World Health Organization. WHO Mortality Database: Tables. Download the detailed data files of the WHO mortality database. 2010; Available at: http://www.who.int/whosis/mort/download/en/index.html, 2009.

(84) Timely Data Resources. ICD-9 and -10 Tools. Available at: http://www.tdrdata.com/IPD/ipd_ICDTranslator.aspx, 2008.

(85) Central Intelligence Agency. The World Factbook. Available at: https://www.cia.gov/library/publications/the-world-factbook/, 2009.

(86) World Health Organization. WHO Mortality Database: Tables. Table 1: Number of registered deaths. 2010; Available at: http://apps.who.int/whosis/database/mort/table1.cfm, 2009.

(87) Hoorn SV, Ezzati M, Rodgers A, Lopez AD, Murray CJL. Estimating attributable burden of disease from exposure and hazard data. In: Comparative quantification of health risks: Global and regional burden of disease due to selected major risk factors. 2004.

(88) Murray CJL, Ezzati M, Lopez AD, Rodgers A, Hoorn SV. Comparative quantification of health risks: Conceptual framework and methodological issues. In: Comparative quantification of health risks: Global and regional burden of disease due to selected major risk factors. 2004.

(89) Corbett JJ, Winebrake JJ, Green EH, Kasibhatla P, Eyring V, Lauer A. Mortality from Ship Emissions: A Global Assessment. Environ. Sci. Technol. 2007;41(24):8512.

(90) World Health Organization. 2004 Global burden of disease summary tables. 2008.

(91) Daniels MJ, Dominici F, Samet JM, Zeger SL. Estimating particulate matter-mortality dose-response curves and threshold levels: an analysis of daily time-series for the 20 largest US cities. Am J Epidemiol 2000;152:397.

(92) Schwartz J, Laden F, Zanobetti A. The concentration-response relation between PM2.5 and daily deaths. Environ. Health Persp. 2002;110:1025.

(93) Künzli N, Kaiser R, Medina S, Studnicka M, Chanel O, Filliger P, et al. Public-health impact of outdoor and traffic-related air pollution: a European assessment. Lancet 2000;356:795.

(94) World Health Organization. Global burden of disease (GB) 2000: version 3 estimates. 2009.

(95) Samoli E, Peng R, Ramsay T, Pipikou M, Touloumi G, Dominici R, et al. Acute effects of ambient particulate matter on mortality in Europe and North America: Results from the APHENA study. Environ Health Perspect 2008;116(11):1480.

(96) Anderson R, Atkinson R, Peacock J. Meta-analysis of time-series studies for health impact assessment of ambient air pollution in Europe. Epidemiology 2004;15(4):S61.

(97) Davis DL, Kjellstrom T, Sloof R, McGartland A, Atkinson D, Barbour W, et al. Short term improvements in public health from global-climate policies on fossil fuel combustion: An interim report. Lancet 1997;350(1341).

(98) Qian Z, Qingci H, Hung-Mo L, Lingli K, Duanping L, Gong J, et al. Exploring uncertainty of the change from ICD-9 to ICD-10 on acute mortality effects of air pollution. Environ Sci 2008;34(248).

APPENDICES

APPENDIX A: Country-level concentrations of fine particulate matter ($PM_{2.5}$) for 231 countries

Country	WHO Subregion	Mean $PM_{2.5\text{-Total}}$ (ug/m^3)[b]	Weighted $PM_{2.5\text{-Total}}$ (ug/m^3)[c]	Mean $PM_{2.5\text{-No Dust}}$ (ug/m^3)[b]	Weighted $PM_{2.5\text{-No Dust}}$ (ug/m^3)[c]	Geographic Coverage (proportion)	Population Coverage (proportion)	Total 2005 Population (# people)[e]
Afghanistan	EMR-D	26 1	25 9	4 2	5 4	0 89	0 94	26,253,470
Albania	EUR-B	13	13 6	7 5	7 9	0 99	1	3,246,356
Algeria	AFR-D	31 9	16 9	1 2	2 4	0 98	0 99	33,086,840
American Samoa	WPR-B	3 7	3 9	1 2	1 2	0 58	0 79	79,210
Andorra	EUR-A	11 4	11 6	7	7 1	1	1	100,463
Angola	AFR-D	8 2	7 7	7 8	7 3	1	0 99	15,288,010
Anguilla	AMR-B[a]	10 5	10 2	1 9	1 9	0 53	0 83	12,976
Antigua and Barbuda	AMR-B	8 8	9 4	1 4	1 5	0 85	0 98	65,863
Argentina	AMR-B	6 1	6 2	2 6	3	0 99	0 99	39,413,650
Armenia	EUR-B	18	21 5	6 5	7 8	1	1	3,779,780
Aruba	AMR-B[a]	13 7	13 7	4	4	0 67	0 91	118,810
Australia	WPR-A	3 9	3 9	1 7	2 4	0 74	0 98	20,109,280
Austria	EUR-A	14	15 6	11 7	13	1	1	8,057,643
Azerbaijan	EUR-B	14 5	14 3	5 4	5 3	1	1	8,262,485
Bahamas	AMR-B	8 7	9	5 5	6 1	0 7	0 78	323,769
Bahrain	EMR-B	36 8	37 6	4 7	4 8	0 78	0 93	695,829
Bangladesh	SEAR-D	23 8	25 3	18 4	19 6	0 99	1	151,982,300
Barbados	AMR-B	11	11 1	1 3	1 3	0 88	0 94	272,214
Belarus	EUR-C	11 4	12	9 9	10 3	1	1	9,959,799
Belgium	EUR-A	18 1	20 6	15 4	17 5	1	1	10,339,980
Belize	AMR-B	8 3	8 3	6 4	6 3	0 94	0 99	252,511
Benin	AFR-D	19 9	17 1	2 5	3 3	1	0 99	7,212,134
Bermuda	AMR-B[a]	7 4	7 4	4 8	4 8	0 78	0 85	64,967
Bhutan	SEAR-D	9 9	12 8	6 8	8 9	0 91	0 97	2,439,303
Bolivia	AMR-D	7 2	6 1	6 9	5 8	1	1	9,278,495
Bosnia and Herzegovina	EUR-B	11 9	11 8	8 4	8 4	1	1	4,195,969
Botswana	AFR-E	6	5 2	5 3	4 6	1	1	1,585,545
Brazil	AMR-B	4 6	4 1	3 7	3 4	1	0 99	181,036,600
British Virgin Islands	AMR-B[a]	11 2	11 5	2 4	2 5	0 73	0 88	26,786
Brunei Darussalam	WPR-A	5 9	6 6	5 5	6 1	0 93	0 92	347,266

Bulgaria	EUR-B	14 1	15 1	10	10 7	1	1	7,581,802
Burkina Faso	AFR-D	23 9	23 8	1 1	1 1	1	1	13,406,320
Burundi	AFR-E	11 1	11 7	9 5	10	1	1	7,370,431
Cambodia	WPR-B	10 5	13	9 2	11 4	0 99	1	14,840,440
Cameroon	AFR-D	16	17 5	5 5	5 2	0 99	0 95	16,560,680
Canada	AMR-A	3 8	9 3	2 7	8 5	0 92	1	31,989,140
Cape Verde	AFR-D	24 4	23 6	1 1	1	0 71	0 9	475,102
Cayman Islands	AMR-B[a]	12 1	11 9	7 8	7 7	0 51	0 79	44,907
Central African Republic	AFR-E	14 4	14 2	6 7	7 5	1	1	4,041,142
Chad	AFR-D	33 2	24 3	1 5	2 5	1	1	9,206,265
Chile	AMR-B	7	9 6	4 8	6 7	0 84	0 94	16,128,430
China	WPR-B	27	51 5	16 9	44 8	0 95	0 99	1,299,135,000
Colombia	AMR-B	6 4	7 8	4 8	5 9	0 98	0 99	45,564,860
Comoros	AFR-D	2 6	2 5	1 4	1 3	0 66	0 76	816,803
Congo, Democratic Republic of	AFR-E	11 8	12 2	10 2	10 7	1	1	60,079,130
Congo, Republic of the	AFR-E	11 3	12 1	9	10 7	1	0 98	3,642,347
Cook Islands	WPR-B	3 6	3 9	1 2	1 2	0 24	0 7	20,264
Costa Rica	AMR-B	5 8	6 4	4 6	5 1	0 96	0 99	4,457,808
Croatia	EUR-A	14 5	15 1	10 7	11 4	0 98	0 99	4,465,522
Cuba	AMR-A	7 5	7 5	5 2	5 2	0 92	0 96	11,369,180
Cyprus	EUR-A	16 4	16 8	4 8	4 8	0 91	0 97	814,315
Czech Republic	EUR-A	16 6	18	14 3	15 5	1	1	10,237,880
Denmark	EUR-A	12 1	13 1	10 2	11 1	0 97	0 99	5,364,561
Djibouti	EMR-D	23 4	24 3	3 6	3 8	0 98	0 97	665,390
Dominica, Commonwealth of	AMR-B	8 3	8 3	1 1	1 1	0 8	0 95	70,301
Dominican Republic	AMR-B	7 6	7 7	3 6	3 6	0 96	0 98	9,048,305
East Timor	SEAR-D	3 9	3 9	2 5	2 5	0 93	0 96	744,357
Ecuador	AMR-D	6 2	7 7	5 7	7 1	0 98	0 99	13,801,730
Egypt	EMR-D	35 6	33 7	3 2	4 7	0 99	0 99	73,907,530
El Salvador	AMR-B	7 2	6 9	5 8	5 7	0 94	0 99	6,855,056
Equatorial Guinea	AFR-D	7 6	8 6	4 6	5	0 97	0 97	521,810
Eritrea	AFR-E	23 8	19 3	2 7	2 4	0 99	1	4,529,318
Estonia	EUR-C	6 9	7	5 8	5 9	0 97	0 99	1,314,608

Ethiopia	AFR-E	11 2	10 6	3 4	3 6	0 95	0 98	70,973,600
Faeroe Islands	EUR-A[a]	6 9	7 6	3 6	3 9	0 53	0 57	48,510
Falkland Islands	AMR-B[a]	7 2	8	1	1 1	0 92	0 95	2,459
Fiji	WPR-B	3 5	3 5	1 2	1 2	0 11	0 08	857,675
Finland	EUR-A	4 3	5 9	3 4	4 8	1	1	5,186,585
France	EUR-A	12 2	14 3	9 1	11	0 99	1	60,274,400
French Guiana	AMR-B[a]	6 9	8 7	1 1	1 2	0 99	0 99	192,611
French Polynesia	WPR-B[a]	3 2	2 3	1 3	0 8	0 51	0 87	252,229
Gabon	AFR-D	8 1	8 5	6 1	6 3	0 97	0 97	1,396,148
Gambia	AFR-D	25 2	25 3	2 2	2 2	0 98	0 97	1,444,073
Georgia	EUR-B	12 3	13 6	5	5 5	0 99	1	5,135,604
Germany	EUR-A	15 9	17	13 7	14 6	1	1	81,860,550
Ghana	AFR-D	15 8	14 1	2 8	2 9	0 98	0 97	21,592,910
Gibraltar	EUR-A[a]	11 4	11 4	2 6	2 6	1	1	33,897
Greece	EUR-A	14 2	15 4	7 2	7 7	0 93	0 99	10,645,640
Greenland	EUR-A[a]	4 1	3	2 1	1 4	0 63	0 89	56,676
Grenada	AMR-B	8 8	8 5	1 2	1 1	0 76	0 98	94,832
Guadeloupe	AMR-B[a]	9 1	9 4	1 3	1 4	0 75	0 94	451,104
Guam	WPR-A[a]	4 6	4 5	1 8	1 7	0 85	0 98	172,710
Guatemala	AMR-D	8 5	7 8	7 4	6 8	0 99	1	12,940,470
Guernsey	EUR-A[a]	13 3	13 8	10 2	10 6	0 5	0 84	56,253
Guinea	AFR-D	19 1	18 2	2 5	2 5	1	1	8,752,810
Guinea-Bissau	AFR-D	22 4	22 5	2 3	2 3	0 95	0 99	1,359,659
Guyana	AMR-B	6 7	9 5	1 5	1 7	0 98	0 85	767,858
Haiti	AMR-D	8 7	9 3	4 7	5 1	0 92	0 98	8,776,608
Honduras	AMR-B	7 6	8 2	5 3	6	0 98	1	7,222,682
Hong Kong	WPR-B	28 2	26	26	23 9	0 77	0 79	7,200,719
Hungary	EUR-C	15 4	16	12 3	12 9	1	1	9,725,342
Iceland	EUR-A	4 2	3 7	1 9	1 6	0 97	0 99	288,745
India	SEAR-D	23 1	29 2	12 7	17 7	0 95	0 99	1,089,212,000
Indonesia	SEAR-B	8 8	12 3	8	11	0 92	0 98	225,305,700
Iran	EMR-B	24 2	22 8	3 4	4 2	0 99	0 98	75,330,700
Iraq	EMR-D	33	31 6	4 5	4 6	1	1	26,323,210
Ireland	EUR-A	8 3	9 6	5 5	6 6	0 98	1	3,998,532
Isle of Man	EUR-A[a]	9	9 3	6 7	6 9	0 93	1	78,551
Israel	EUR-A	27 6	23 3	4 9	4 7	0 99	0 98	6,779,539
Italy	EUR-A	14 6	18 3	9 8	12 6	0 98	0 98	57,136,100
Ivory Coast	AFR-E	14 2	12 4	2 7	2 7	0 96	0 98	17,744,250
Jamaica	AMR-B	7 9	8 2	4 7	4 8	0 92	0 98	2,693,061
Japan	WPR-A	10 3	16 7	7 9	12 9	0 95	0 99	127,980,100

Jersey	EUR-A[a]	13 2	13 3	10 1	10 2	0 63	0 66	88,459
Jordan	EMR-B	29 3	24 1	4 2	4 2	1	1	5,639,327
Kazakhstan	EUR-C	9	10	4 5	4 7	1	1	15,949,650
Kenya	AFR-E	5 9	4 8	2 7	2 8	0 97	0 99	33,725,080
Kiribati	WPR-B	4 3	3 8	2 5	2	0 43	0 65	88,666
Korea	WPR-B	16 9	21 1	14	17 6	0 97	1	48,308,970
Korea, Democratic People's Republic of (north)	SEAR-D	14 3	19 4	12	16 3	0 99	0 99	23,001,480
Kuwait	EMR-B	36 5	41 4	4 5	5 3	0 99	0 95	2,171,708
Kyrgyz Republic	EUR-B	17 6	16 8	4	4 1	0 73	0 9	5,309,561
Lao People's Democratic Republic	WPR-B	14 4	15 3	13 2	13 9	1	1	5,909,750
Latvia	EUR-C	8 4	8 7	7 2	7 4	0 99	0 99	2,357,923
Lebanon	EMR-B	19 4	20 5	4 4	4 7	0 98	0 94	3,763,262
Lesotho	AFR-E	4 9	5	4 2	4 4	0 97	0 99	2,085,057
Liberia	AFR-D	10 2	10 1	2 2	2 2	0 93	0 93	3,864,037
Libyan Arab Jamahiriya	EMR-B	34	25	1 9	2 5	0 98	0 99	5,905,406
Liechtenstein	EUR-A[a]	12 8	13	10 6	10 8	1	1	38,042
Lithuania	EUR-C	9 8	10 3	8 4	8 8	1	1	3,656,143
Luxembourg	EUR-A	12 4	12 7	10 5	10 7	1	1	463,573
Macao	WPR-B	51 4	51 4	47 4	47 4	0 75	1	248,201
Macedonia	EUR-B	14 7	16 4	9 2	10 4	1	1	2,069,490
Madagascar	AFR-D	1 8	2 1	1 3	1 4	0 99	1	18,399,600
Malawi	AFR-E	5 6	5 5	5 1	5	1	1	12,522,840
Malaysia	WPR-B	8 8	12 6	8 2	11 7	0 97	0 98	24,342,170
Maldives	SEAR-D	8 6	6 6	4 3	3 2	0 09	0 08	338,173
Mali	AFR-D	36 5	26 7	0 8	1	0 99	1	13,123,150
Malta	EUR-A	14 2	14 2	4 1	4 1	0 97	1	397,705
Marshall Islands	WPR B	4 5	4 1	1 4	1 3	0 37	0 5	54,589
Martinique	AMR-B[a]	9 3	9 2	1 2	1 2	0 8	0 89	393,913
Mauritania	AFR-D	43 8	41 8	0 9	1 1	1	0 99	3,087,062
Mauritius	AFR-D	3 4	3 3	1 2	1 2	0 8	0 88	1,208,794
Mayotte	AFR-D[a]	2 3	2 3	1 4	1 3	0 74	0 95	198,459
Mexico	AMR-B	9 9	14 3	8 3	13 1	0 99	1	106,129,600
Micronesia, Federated States of	WPR-B	4 5	4 8	1 8	2	0 46	0 71	138,532
Moldova,	EUR-C	11 8	12	9 5	9 7	1	1	4,222,484

Republıc of								
Monaco	EUR-A	13 7	13 7	9 7	9 7	1	1	32,943
Mongolıa	WPR-B	9 2	7 8	3 7	3 7	1	1	2,687,887
Montserrat	AMR-B[a]	10 5	10 5	1 6	1 6	0 36	0 46	4,461
Morocco (ıncludes Western Sahara)	EMR-D	30 2	15 8	1 4	1 9	0 99	0 97	32,699,760
Mozambıque	AFR-E	4 2	4 3	3 5	3 5	0 99	0 99	20,076,830
Myanmar	SEAR-D	9 3	10 9	7 6	9	0 99	1	50,700,530
Namıbıa	AFR-E	6	6 7	4 2	5 7	0 96	0 99	1,896,222
Nauru	WPR-B	3 3	3 3	1 9	1 9	0 5	0 7	13,730
Nepal	SEAR-D	20 9	28 4	12 5	18 1	0 91	0 99	25,987,460
Netherland Antılles	AMR-B[a]	12	12 3	3	3 1	0 79	0 97	218,578
Netherlands, Kıngdom of the	EUR-A	19 1	19 6	16 4	16 8	0 99	1	16,127,410
New Caledonıa	WPR-B[a]	2 5	2 4	1 2	1 1	0 9	0 89	237,127
New Zealand	WPR-A	2 3	2 9	0 9	1 2	0 94	0 97	3,918,713
Nıcaragua	AMR-D	6 7	6 5	4 3	4 5	0 98	0 99	5,771,017
Nıger	AFR-D	41 1	33 2	0 8	0 8	1	1	12,994,130
Nıgerıa	AFR-D	26 5	24 1	3 7	4 5	0 96	0 94	129,700,400
Nıue	WPR-B	2 6	2 5	0 8	0 8	0 46	0 72	1,890
Norfolk Island	WPR-B[a]	3 5	3 5	1 4	1 4	0 5	0 82	2,089
Northern Marıana Islands	WPR-A[a]	4 4	4 1	1 7	1 5	0 59	0 73	88,971
Norway	EUR-A	4 6	5 5	3 3	4 2	0 98	1	4,550,052
Occupıed Palestınıan Terrıtory	EMR-D[a]	23 3	22 7	4 6	4 4	1	1	3,658,919
Oman	EMR-B	30 8	28 3	3 2	3 1	0 98	0 94	2,998,056
Pakıstan	EMR-D	37 8	40 3	9 8	14 5	0 97	0 99	160,011,900
Palau	WPR-B	4 2	4 1	2 2	2 2	0 62	0 92	21,284
Panama	AMR-B	5 7	5 8	3 8	3 8	0 93	0 98	3,062,620
Papua New Guınea	WPR-B[a]	4 5	4 4	3 5	3 6	0 91	0 97	5,379,373
Paraguay	AMR-B	5 4	3 4	4 8	3	1	1	6,154,333
Peru	AMR-D	6 2	11 9	5 9	11 2	1	0 99	27,797,580
Phılıppınes	WPR-B	6 8	8 6	5 3	6 7	0 9	0 97	83,004,710
Pıtcaırn	WPR-B[a]	3 2	3 2	1	1	0 75	0 96	68
Poland	EUR B	15 1	16 5	13 2	14 4	1	1	38,420,730
Portugal	EUR-A	9 5	11 4	4 2	5 2	0 97	0 98	10,076,600
Puerto Rıco	AMR-B[a]	6 2	6 2	1 6	1 6	0 91	0 98	4,090,826
Qatar	EMR-B	39 2	40	4 7	4 8	0 95	0 95	609,917

Reunion	AFR-D[a]	2 8	2 8	1	1	0 81	0 91	770,775
Romania	EUR-B	13 9	15	10 9	11 7	1	1	22,146,980
Russia	EUR-C	4 6	9 1	3 5	7 2	0 98	1	140,946,300
Rwanda	AFR-E	12 5	12 9	10 3	10 6	1	1	8,444,366
Saint Helena	AFR-D[a]	4 7	4	1 9	2	0 59	0 86	6,559
Saint Kitts and Nevis	AMR-B	10 7	10 8	1 7	1 7	0 64	0 84	37,180
Saint Lucia	AMR-B	8 6	8 5	1 1	1 1	0 7	0 8	155,910
Saint Pierre and Miquelon	AMR-B[a]	4 7	5 1	3 2	3 5	0 69	0 44	7,099
Saint Vincent and Grenadines	AMR-B	9 6	9	1 2	1 1	0 71	0 89	116,807
San Marino	EUR-A	14 2	14 2	9 8	9 8	1	1	24,753
Sao Tome and Principe	AFR-D	6 3	6 2	4 4	4 4	0 74	0 91	150,362
Saudi Arabia	EMR-B	36 3	33 3	3 6	3 5	0 98	0 99	23,787,970
Senegal	AFR-D	28 5	29	1 8	1 9	0 99	0 94	10,705,600
Serbia and Montenegro, Former	EUR-B	14 1	14 2	10	10	1	1	10,659,970
Seychelles	AFR-D	3 5	3 3	1 4	1 3	0 5	0 61	85,762
Sierra Leone	AFR-D	15 8	15 8	2 6	2 7	0 99	0 98	5,529,360
Singapore	WPR-A	19	19 5	17 6	18	0 87	0 96	4,278,921
Slovakia	EUR-B	14 1	14 8	11 8	12 4	1	1	5,421,965
Slovenia	EUR-A	14 6	15 4	11 7	12 4	1	1	2,209,206
Solomon Islands	WPR-B	3 7	3 6	2	1 9	0 77	0 92	528,178
Somalia	EMR-D	13 8	9 4	2 1	2 1	0 93	0 96	10,830,560
South Africa	AFR-E	5	6 7	3 6	5 7	0 99	1	44,994,500
Spain	EUR-A	11 2	12 3	5 2	5 6	0 99	0 99	39,804,340
Sri Lanka	SEAR-B	6 8	6 7	3 7	3 7	0 96	0 96	19,837,500
Sudan	EMR-D	26 8	24 3	2 8	2 7	1	1	34,865,290
Suriname	AMR-B	5 4	9 2	1 1	1 3	0 99	0 99	427,524
Svalbard	EUR-A[a]	3 3	3 3	1 8	1 7	0 45	0 12	2,411
Swaziland	AFR E	6 1	6	5 2	5 1	1	1	966,282
Sweden	EUR-A	4 7	7 2	3 7	5 9	1	1	8,786,058
Switzerland	EUR-A	14 5	15 6	11 8	12 7	1	1	7,123,490
Syrian Arab Republic	EMR-B	30 6	28 2	6 5	6 7	1	1	18,369,530
Taiwan	WPR-B[a]	14 4	19 3	11 9	16	0 93	0 97	22,424,600
Tajikistan	EUR-B	23 9	24 7	5 7	6 4	0 48	0 79	6,290,289
Tanzania, United Republic of	AFR-E	5 6	5 9	4 3	4 3	1	0 99	39,430,070
Thailand	SEAR-B	15 2	17 5	13 5	15 5	0 99	0 99	66,466,950

Togo	AFR-D	17	16 1	2 8	2 9	1	0 96	5,116,611
Tokelau	WPR-B[a]	3 7	3 6	1 9	1 9	0 43	0 48	1,418
Tonga	WPR-B	3 2	3 1	1	1	0 42	0 88	100,882
Trinidad and Tobago	AMR-B	7 5	7	1 2	1 2	0 8	0 9	1,324,092
Tunisia	EMR-B	23 7	17 2	2 6	3 1	0 97	0 99	10,014,230
Turkey	EUR-B	17 4	16 6	7	7 1	0 98	0 99	71,235,730
Turkmenistan	EUR-B	16 5	16 1	3 3	3 3	1	1	5,268,055
Turks and Caicos Islands	AMR-B[a]	9 4	9 3	4 3	4 2	0 67	0 79	19,577
Tuvalu	WPR-B	3 4	3 4	1 8	1 8	0 04	0 02	10,866
Uganda	AFR-E	8	8 5	5 8	6 3	1	1	27,320,650
Ukraine	EUR-C	11 5	12 5	9 3	10 1	1	1	47,308,990
United Arab Emirates	EMR-B	38 3	36 2	4 1	4 3	0 97	0 98	2,829,366
United Kingdom	EUR-A	11 1	14 9	8 7	12 1	0 97	1	59,928,530
United States of America	AMR-A	7	11 6	5 6	10 4	0 99	1	296,065,100
Uruguay	AMR-B	2	3 6	1	1 5	0 99	0 99	3,457,158
Uzbekistan	EUR-B	14 9	18 1	4 1	4 9	0 99	0 99	26,477,500
Vanuatu	WPR-B	4 1	3 7	1 6	1 5	0 79	0 88	223,247
Venezuela	AMR-B	6 8	8 8	2 9	3 7	0 98	0 98	26,477,950
Viet Nam	WPR-B	17 9	23 7	16 2	21 5	0 97	0 97	83,372,510
Virgin Islands, The U S	AMR-B[a]	11 9	11 6	2 5	2 5	0 82	0 91	127,692
Wallis and Futuna	WPR-B[a]	3 7	3 7	1 2	1 2	0 55	0 5	14,867
Western Samoa	WPR-B	2 3	2 5	0 8	0 8	0 76	0 91	161,389
Yemen	EMR-D	26 8	19 9	3 1	2 7	0 99	0 99	22,482,590
Zambia	AFR-E	7 4	7 2	7 1	6 9	1	1	11,569,010
Zimbabwe	AFR E	4 7	4 6	4 3	4 1	1	1	13,745,810

[a] Subregions were not specified for these countries/regions in the 2004 World Health Report; subregions were assigned according to geographic location and mortality

[b] $PM_{2.5}$ values were not population weighted; data was standardized to 35% relative humidity, and adjusted for sampling to better represent a true annual sample

[c] $PM_{2.5}$ values were weighted to population using 2005 population grids; data was standardized to 35% relative humidity, and adjusted for sampling to better represent a true annual sample

[d] Values had dust (and sea salt) fraction removed and thus better represent $PM_{2.5}$ from combustion sources

[e] Size of the population represented by weighted $PM_{2.5}$ values

APPENDIX B: Availability of WHO mortality data by source for 231 countries with $PM_{2.5}$ exposure data

WHO Mortality Database (n= 132)	WHOSIS Mortality Data Only (n= 79)	No WHO Mortality Data (n= 20)
Albania	Afghanistan	American Samoa
Anguilla	Algeria	Faeroe Islands
Antigua and Barbuda	Andorra	French Polynesia
Argentina	Angola	Gibraltar
Armenia	Bangladesh	Greenland
Aruba	Benin	Guam
Australia	Bhutan	Guernsey
Austria	Bolivia	Isle of Man
Azerbaijan	Botswana	Jersey
Bahamas	Burkina Faso	Liechtenstein
Bahrain	Burundi	Mayotte
Barbados	Cambodia	New Caledonia
Belarus	Cameroon	Norfolk Island
Belgium	Central African Republic	Northern Mariana Islands
Belize	Chad	Occupied Palestinian Territory
Bermuda	Comoros	Pitcairn
Bosnia-Herzegovina	Congo, Democratic Republic of	Saint Helena
Brazil	Congo, Republic of the	Svalbard
British Virgin Islands	Cook Islands	Tokelau
Brunei Darussalam	Djibouti	Wallis and Futuna
Bulgaria	East Timor	
Canada	Equatorial Guinea	
Cape Verde	Eritrea	
Cayman Islands		
Chile	Ethiopia	
China	Gabon	
Colombia	Gambia	
Costa Rica	Ghana	
Croatia	Guinea, Republic of	
Cuba	Guinea-Bissau	
Cyprus	India	
Czech Republic	Indonesia	
Denmark	Iraq	
Dominica, Commonwealth of	Ivory Coast	

Dominican Republic	Jordan
Ecuador	Kenya
Egypt	Korea, Democratic People's Republic of (north)
El Salvador	Lao People's Democratic Republic
Estonia	Lebanon
Falkland Islands	Lesotho
Fiji	Liberia
Finland	Libya
France	Madagascar
French Guiana	Malawi
Georgia	Malaysia
Germany	Mali
Greece	Marshall Islands
Grenada	Mauritania
Guadeloupe	Micronesia, Federated States of
Guatamala	Morocco (includes Western Sahara)
Guyana	Mozambique
Haiti	Myanmar (Burma), Union of
Honduras	Namibia
Hong Kong	Nauru
Hungary	Nepal
Iceland	Niger, Republic of
Iran	Nigeria
Ireland	Niue
Israel	Oman
Italy	Palau
Jamaica	Rwanda
Japan	Saudi Arabia
Kazakhstan	Senegal
Kiribati	Sierra Leone
Korea, Republic of (south)	Solomon Islands
Kuwait	Somalia
Kyrgyz Republic (Kyrgyzstan)	Sudan
Latvia	Togo

Lithuania
Luxembourg
Macao
Macedonia, The Former Yugoslave Republic
Maldives
Malta
Martinique
Mauritius
Mexico
Moldova, Republic of
Monaco
Mongolia
Montserrat
Netherlands Antilles
Netherlands, Kingdom of the
New Zealand
Nicaragua
Norway
Pakistan
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Puerto Rico
Qatar
Reunion
Romania
Russia
Saint Kitts and Nevis
Saint Lucia
Saint Pierre and Miquelon
Saint Vincent and Grenadines
San Marino
Sao Tome and Principe
Serbia and Montenegro, Former
Seychelles
Singapore
Slovakia
Slovenia
South Africa
Tonga
Tunisia
Tuvalu
United Arab Emirates
Vanuatu
Vietnam
Western Samoa
Yemen
Zambia

Spain
Sri Lanka
Suriname
Sweden
Switzerland
Syria
Tajikistan
Thailand
Trinidad and Tobago
Turkey
Turkmenistan
Turks and Caicos Islands
Ukraine
United Kingdom
United States of America
Uruguay
Uzbekistan
Thailand
Trinidad and Tobago
Turkey

APPENDIX C: Year of mortality data employed in the current analysis, ICD coding used by each country, and other details for the 132 countries with data in the WHO Mortality Database

Country	WHO Country Code	Year of Mortality Data Collected	Most Recent Year of Mortality Data[a]	ICD Revision Used	Coverage (%)[b]
Albania	4005	2004		9	70.8
Anguilla	2005	2005	2006	10	N/A
Antigua and Barbuda	2010	2004		10	77.4
Argentina	2020	2005		10	100.0
Armenia	4007	2003		9	62.1
Aruba	2025	1999		10	N/A
Australia	5020	2003		10	100.0
Austria	4010	2005	2006	10	100.0
Azerbaijan	4012	2004		10	70.5
Bahamas	2030	2000		10	82.4
Bahrain	3020	2001		10	86.5
Barbados	2040	2001		10	92.0.
Belarus	4018	2003		10	99.1
Belgium	4020	1997		9	100.0
Belize	2045	2001		10	86.3
Bermuda	2050	2002		10	N/A
Bosnia-Herzegovina	4025	1991		9	100.0
Brazil	2070	2004		10	79.7
British Virgin Islands	2085	2003		10	N/A
Brunei Darussalam	3030	2000		10	100.0
Bulgaria	4030	2004		9	100.0
Canada	2090	2004		10	100.0
Cape Verde	1060	1980		8	N/A
Cayman Islands	2110	2004		10	N/A
Chile	2120	2005		10	94.5
China[c]	3068	2000		9	N/A
Colombia	2130	2005		10	78.9
Costa Rica	2140	2005		10	87.1
Croatia	4038	2005	2006	10	96.8
Cuba	2150	2005		10	100.0
Cyprus	3080	2006		10	92.3
Czech Republic	4045	2005		10	100.0
Denmark	4050	2001		10	100.0
Dominica, Commonwealth of	2160	2004		10	100.0
Dominican Republic	2170	2004		10	49.7

Ecuador	2180		2005		10	75.0
Egypt	1125		2000		10	81.1
El Salvador	2190		2005		10	75.0
Estonia	4055		2005		10	100.0
Falkland Islands	2200		1983		9	N/A
Fiji	5070		1999		9	69.4
Finland	4070	2005		2006	10	100.0
France	4080		2005		10	98.2
French Guiana	2210		2005		10	N/A
Georgia	4084		2001		10	98.4
Germany	4085	2005		2006	10	100.0
Greece	4140	2005		2006	9	100.0
Grenada	2230		2002		10	74.8
Guadeloupe	2240		2005		10	N/A
Guatamala	2250		2004		9	88.7
Guyana	2260		2005		10	71.1
Haiti	2270		2003		10	8.7
Honduras	2280		1990		9	N/A
Hong Kong	3090	2005		2006	10	N/A
Hungary	4150		2005		10	100.0
Iceland	4160	2005		2006	10	97.2
Iran	3130		1987		8	N/A
Ireland	4170	2005		2006	9	99.3
Israel	3150		2004		10	100.0
Italy	4180		2003		10	100.0
Jamaica	2290		1991		9	60.1
Japan	3160	2005		2006	10	100.0
Kazakhstan	4182	2005		2006	10	80.4
Kiribati	5105		2001		10	70.5
Korea, Republic of (south)	3325	2005		2006	10	91.3
Kuwait	3190		2002		10	100.0
Kyrgyz Republic (Kyrgyzstan)	4184	2005		2006	10	76.0
Latvia	4186	2005		2006	10	95.2
Lithuania	4188	2005		2006	10	97.2
Luxembourg	4190		2005		10	100.0
Macao	3220		1994		9	N/A
Macedonia, The Former Yugoslave Republic	4195		2003		9	89.2
Maldives	3255		2005		10	49.8
Malta	4200		2005		10	96.3
Martinique	2300		2005		10	N/A
Mauritius	1300		2005		10	94.8
Mexico	2310		2005		10	95.4
Moldova, Republic of	4260	2005		2006	10	83.2
Monaco	4205		1987		9	N/A
Mongolia	3260		1994		9	84.2

Montserrat	2320		2003		10	N/A
Netherlands Antilles	2330		1981		9	N/A
Netherlands, Kingdom of the	4210	2005		2006	10	100.0
New Zealand	5150		2004		10	100.0
Nicaragua	2340		2005		10	58.7
Norway	4220		2005		10	100.0
Pakistan[d]	3290		1994		9	N/A
Panama	2350		2004		10	89.9
Papua New Guinea	5195		1980		9	N/A
Paraguay	2360		2004		10	75.5
Peru	2370		2000		10	54.8
Philippines	3300		1998		9	85.0
Poland	4230	2005		2006	10	99.7
Portugal	4240		2003		10	100.0
Puerto Rico	2380		2005		10	N/A
Qatar	3320		1995		10	77.3
Reunion	1360		2005		10	N/A
Romania	4270	2005		2007	10	100.0
Russia	4272	2005		2006	10	100.0
Saint Kitts and Nevis	2385		2005		10	100.0
Saint Lucia	2400		2002		10	97.5
Saint Pierre and Miquelon	2410		2005		10	N/A
Saint Vincent and Grenadines	2420		2003		10	92.2
San Marino	4275		2005		9	80.2
Sao Tome and Principe	1385		1987		9	N/A
Serbia and Montenegro, Former[e]	4350		2002		10	83.1
Seychelles	1400		2005		10	100.0
Singapore	3350	2005		2006	9	76.6
Slovakia	4274		2005		10	98.5
Slovenia	4276	2005		2006	10	100.0
South Africa	1430		2005		10	76.9
Spain	4280		2005		10	100.0
Sri Lanka	3365		1995		9	76.5
Suriname	2430		2000		10	70.0
Sweden	4290		2005		10	100.0
Switzerland	4300		2005		10	100.0
Syria	3370		1985		9	N/A
Taiwan	3070		1969		7	N/A
Tajikistan	4301		2005		9	54.7
Thailand	3380		2002		10	85.2

Trinidad and Tobago	2440	2002	10	84.6
Turkey	3400	1987	8	N/A
Turkmenistan	4302	1998	9	76.0
Turks and Caicos Islands	2445	2005	10	N/A
Ukraine	4303	2005	10	99.8
United Kingdom	4308	2005 2006	10	100.0
United States of America	2450	2005	10	99.9
Uruguay	2460	2004	10	99.1
Uzbekistan	4335	2005	10	72.7
Venezuela	2470	2005	10	100.0
Virgin Islands, The United States	2455	2005	10	N/A
Zimbabwe	1570	1990	9	50.0

[a] Latest available country-year of mortality data as of 21 July 2008

[b] Coverage was calculated by dividing total deaths reported for a country-year from the vital registration system by the number of estimated deaths for that year for the national population

[c] China's data was gathered from selected urban and rural areas and represents less than 10% of all deaths occurring in the country

[d] Pakistan's data was based on a survey of the country

[e] Serbia and Montenegro's data excludes Kosovo and Methohia

[f] Syria's data only represents part of the country

APPENDIX D: Aggregated Country Mortality Data for All Cause, Lung Cancer, Ischemic Heart Disease, and Cardiopulmonary Disease Mortalities Adjusted for Coverage, by Subregion

Table D1 All cause (AC) mortality adjusted for coverage, by subregion

WHO Subregion	Country	Year of Mortality Data Collection	All-Cause Mortality for All Ages[a]			All-Cause Mortality for Adults (20+)[a]		
			Male[b]	Female[b]	Total	Male[b]	Female[b]	Total
AFR-D	Cape Verde	1980	1087	1194	**2281**	517	688	**1205**
AFR-D	Mauritius	2005	4979	3881	**8860**	4758	3713	**8471**
AFR-D	Reunion	2005	2486	1879	**4365**	2367	1809	**4176**
AFR-D	Sao Tome and Principe	1987	530	476	**1006**	274	247	**521**
AFR-D	Seychelles	2005	386	287	**673**	368	276	**644**
AFR-D	**5**		**9468**	**7717**	**17185**	**8284**	**6733**	**15017**
AFR-E	South Africa	2005	367277	360506	**727783**	314460	312628	**627089**
AFR-E	Zimbabwe	1990	32378	19866	**52244**	22820	11547	**34367**
AFR-E	**2**		**399654**	**380372**	**780027**	**337280**	**324175**	**661455**
AMR-A	Canada	2004	114513	112071	**226584**	112457	110678	**223135**
AMR-A	Cuba	2005	45878	38946	**84824**	44852	38246	**83098**
AMR-A	United States of America	2005	1208883	1241582	**2450465**	1176328	1220582	**2396911**
AMR-A	**3**		**1369274**	**1392599**	**2761873**	**1333637**	**1369506**	**2703144**
AMR-B	Anguilla	2005	34	22	**56**	33	22	**55**
AMR-B	Antigua and Barbuda	2004	327	299	**626**	289	278	**568**
AMR-B	Argentina	2005	155516	137645	**293161**	146489	131357	**277845**
AMR-B	Aruba	1999	297	255	**552**	288	241	**529**
AMR-B	Bahamas	2000	1055	856	**1911**	981	797	**1778**
AMR-B	Barbados	2001	847	1002	**1849**	819	977	**1796**
AMR-B	Belize	2001	865	569	**1434**	719	470	**1188**
AMR-B	Bermuda	2002	208	210	**418**	207	209	**416**
AMR-B	Brazil	2004	714697	517258	**1231955**	645963	473284	**1119247**

AMR-B	British Virgin Islands	2003	65	39	**104**	62	38	**100**
AMR-B	Cayman Islands	2004	86	76	**162**	82	75	**157**
AMR-B	Chile	2005	48919	41918	**90838**	46702	40443	**87145**
AMR-B	Colombia	2005	132489	96193	**228682**	117033	86069	**203103**
AMR-B	Costa Rica	2005	9922	7599	**17521**	9130	7052	**16182**
AMR-B	Dominica, Commonwealth of	2004	285	272	**557**	278	255	**533**
AMR-B	Dominican Republic	2004	27081	18909	**45990**	23653	16239	**39893**
AMR-B	El Salvador	2005	22669	15998	**38666**	20401	14646	**35048**
AMR-B	Falkland Islands	1983	13	5	**18**	11	5	**16**
AMR-B	French Guyana	2005	452	288	**740**	379	233	**612**
AMR-B	Grenada	2002	545	567	**1112**	510	528	**1038**
AMR-B	Guadeloupe	2005	1597	1330	**2927**	1551	1288	**2839**
AMR-B	Guyana	2005	3801	2943	**6744**	3413	2617	**6030**
AMR-B	Honduras	1990	9734	7349	**17083**	7259	5191	**12450**
AMR-B	Jamaica	1991	7706	7937	**15642**	7142	7499	**14641**
AMR-B	Martinique	2005	1349	1268	**2617**	1300	1232	**2532**
AMR-B	Mexico	2005	284835	231844	**516679**	252684	208284	**460968**
AMR-B	Montserrat	2003	30	25	**55**	30	25	**55**
AMR-B	Netherlands Antilles	1981	444	449	**893**	375	396	**771**
AMR-B	Panama	2004	8580	6255	**14835**	7530	5475	**13005**
AMR-B	Paraguay	2004	15084	12041	**27125**	12888	10396	**23284**
AMR-B	Puerto Rico	2005	16379	13152	**29531**	15917	12853	**28770**
AMR-B	Saint Kitts and Nevis	2005	179	177	**356**	169	172	**341**
AMR-B	Saint Lucia	2002	500	464	**964**	467	426	**894**
AMR-B	Saint Pierre and Miquelon	2005	28	25	**53**	28	25	**53**
AMR-B	Saint Vincent and Grenadines	2003	458	376	**834**	423	350	**773**
AMR-B	Suriname	2000	1925	1418	**3344**	1689	1230	**2919**

AMR-B	Trinidad and Tobago	2002	6280	4826	**11106**	5895	4512	**10407**
AMR-B	Turks and Caicos Islands	2005	32	21	**53**	29	21	**50**
AMR-B	Uruguay	2004	17015	15467	**32483**	16373	15019	**31392**
AMR-B	Venezuela	2005	135138	88660	**223797**	115832	77319	**193150**
AMR-B	Virgin Islands, U S	2005	373	290	**663**	359	277	**636**
AMR-B	**41**		**1627839**	**1236296**	**2864135**	**1465382**	**1127825**	**2593207**
AMR-D	Ecuador	2005	40794	30272	**71066**	35086	26213	**61299**
AMR-D	Guatamala	2004	43041	31392	**74433**	31548	22614	**54162**
AMR-D	Haiti	2003	4673	4380	**9052**	3630	3460	**7090**
AMR-D	Nicaragua	2005	13720	9958	**23678**	11095	8082	**19177**
AMR-D	Peru	2000	66632	55906	**122539**	55536	47036	**102572**
AMR-D	**5**		**168860**	**131908**	**300768**	**136895**	**107405**	**244300**
EMR-B	Bahrain	2001	1371	876	**2246**	1219	779	**1998**
EMR-B	Iran	1987	49397	31281	**80678**	34015	20514	**54528**
EMR-B	Kuwait	2002	2755	1587	**4342**	2365	1305	**3670**
EMR-B	Qatar	1995	794	433	**1227**	661	346	**1007**
EMR-B	Syria	1985	20268	18948	**39216**	12976	9945	**22921**
EMR-B	**5**		**74584**	**53125**	**127709**	**51236**	**32888**	**84124**
EMR-D	Egypt	2000	249138	205224	**454362**	201182	165527	**366709**
EMR-D	Pakistan	1994	850	808	**1658**	401	351	**752**
EMR-D	**2**		**249988**	**206032**	**456020**	**201583**	**165878**	**367461**
EUR-A	Austria	2005	34986	40203	**75189**	34531	39912	**74443**
EUR-A	Belgium	1997	51888	51912	**103800**	51146	51389	**102535**
EUR-A	Croatia	2005	26900	26547	**53447**	26595	26347	**52942**
EUR-A	Cyprus	2006	2825	2697	**5522**	2780	2669	**5449**
EUR-A	Czech Republic	2005	54072	53866	**107938**	53551	53533	**107084**
EUR-A	Denmark	2001	27877	29755	**57632**	27552	29506	**57058**
EUR-A	Finland	2005	23965	23786	**47751**	23712	23608	**47320**
EUR-A	France	2005	275501	261510	**537011**	271980	259276	**531257**
EUR-A	Germany	2005	388554	441673	**830227**	385101	439377	**824478**
EUR-A	Greece	2005	55435	49656	**105091**	54878	49283	**104161**
EUR-A	Iceland	2005	970	918	**1888**	953	909	**1862**

EUR-A	Ireland	2005	14001	13632	**27633**	13730	13412	**27143**
EUR-A	Israel	2004	18999	18758	**37757**	18287	18260	**36547**
EUR-A	Italy	2003	289826	299071	**588897**	287231	297370	**584601**
EUR-A	Luxembourg	2005	1735	1861	**3596**	1722	1847	**3569**
EUR-A	Malta	2005	1634	1611	**3246**	1609	1592	**3201**
EUR-A	Monaco	1987	252	251	**503**	249	250	**499**
EUR-A	Netherlands, Kingdom of the	2005	66362	70040	**136402**	65453	69353	**134806**
EUR-A	Norway	2005	20065	21087	**41152**	19834	20943	**40777**
EUR-A	Portugal	2003	56226	52922	**109148**	55574	52445	**108019**
EUR-A	San Marino	2005	139	123	**262**	137	122	**259**
EUR-A	Slovenia	2005	9413	9412	**18825**	9312	9347	**18659**
EUR-A	Spain	2005	201769	185586	**387355**	199548	184238	**383786**
EUR-A	Sweden	2005	44828	46947	**91775**	44473	46707	**91180**
EUR-A	Switzerland	2005	29708	31416	**61124**	29338	31178	**60516**
EUR-A	United Kingdom	2005	277349	305615	**582964**	273365	302985	**576350**
EUR-A	**26**		**1975280**	**2040856**	**4016136**	**1952641**	**2025858**	**3978499**
EUR-B	Albania	2004	12854	10076	**22930**	12063	9532	**21596**
EUR-B	Armenia	2003	18448	17425	**35873**	17862	17064	**34926**
EUR-B	Azerbaijan	2004	33721	30470	**64191**	31125	28597	**59723**
EUR-B	Bosnia and Herzegovina	1991	17010	13670	**30680**	16046	13074	**29120**
EUR-B	Bulgaria	2004	59256	50854	**110110**	58389	50264	**108653**
EUR-B	Georgia	2001	19882	20086	**39968**	19351	19771	**39122**
EUR-B	Kyrgyzstan	2005	25295	20575	**45870**	22087	18144	**40231**
EUR-B	Macedonia	2003	10894	9057	**19951**	10568	8846	**19414**
EUR-B	Poland	2005	197376	172013	**369390**	194394	170131	**364525**
EUR-B	Romania	2005	138461	123640	**262101**	135146	121327	**256473**
EUR-B	Serbia and Montenegro, Former	2002	64998	61603	**126600**	63977	60932	**124909**
EUR-B	Slovakia	2005	28573	25704	**54277**	28120	25411	**53530**
EUR-B	Tajikistan	2005	23002	19008	**42011**	19768	16587	**36356**
EUR-B	Turkey	1987	75744	58281	**134025**	59057	45240	**104297**
EUR-B	Turkmenistan	1998	20481	16342	**36823**	15406	12453	**27859**

EUR-B	Uzbekistan	2005	94926	84038	**178965**	83994	76106	**160100**
EUR-B	**16**		**840922**	**732843**	**1573765**	**787353**	**693480**	**1480834**
EUR-C	Belarus	2003	76707	67785	**144492**	75521	67170	**142691**
EUR-C	Estonia	2005	8834	8482	**17316**	8716	8402	**17118**
EUR-C	Hungary	2005	69781	65951	**135732**	69096	65497	**134593**
EUR-C	Kazakhstan	2005	106460	81455	**187914**	100592	77607	**178199**
EUR-C	Latvia	2005	17405	16945	**34350**	17153	16788	**33941**
EUR-C	Lithuania	2005	24039	20987	**45025**	23629	20789	**44418**
EUR-C	Moldova	2005	27281	24916	**52197**	26613	24459	**51072**
EUR-C	Russia	2005	1245035	1058900	**2303935**	1219664	1044259	**2263923**
EUR-C	Ukraine	2005	404247	379278	**783525**	397956	375604	**773560**
EUR-C	**9**		**1979789**	**1724698**	**3704486**	**1938939**	**1700575**	**3639514**
SEAR-B	Sri Lanka	1995	81159	48154	**129313**	76166	45726	**121893**
SEAR-B	Thailand	2002	251963	184695	**436658**	236463	175383	**411846**
SEAR-B	**2**		**333122**	**232849**	**565971**	**312629**	**221110**	**533739**
SEAR-D	Maldives	2005	898	596	**1494**	813	526	**1338**
SEAR-D	**1**		**898**	**596**	**1494**	**813**	**526**	**1338**
WPR-A	Australia	2003	67940	63844	**131784**	66512	62895	**129407**
WPR-A	Brunei	2000	553	412	**965**	485	362	**847**
WPR-A	Japan	2005	584970	498826	**1083796**	580689	495958	**1076647**
WPR-A	New Zealand	2004	14203	14442	**28645**	13803	14147	**27950**
WPR-A	Singapore	2005	10342	8520	**18862**	10190	8410	**18600**
WPR-A	**5**		**678008**	**586044**	**1264052**	**671679**	**581772**	**1253451**
WPR-B	China	2000	394349	317597	**711946**	379942	306973	**686915**
WPR-B	Fiji	1999	2453	1988	**4440**	2130	1704	**3834**
WPR-B	Hong Kong	2005	21571	17113	**38683**	21374	16971	**38344**
WPR-B	Kiribati	2001	373	278	**651**	245	171	**416**
WPR-B	Korea; Republic of (south)	2005	147185	119685	**266870**	144317	117662	**261979**
WPR-B	Macao	1994	726	603	**1329**	690	583	**1273**
WPR-B	Mongolia	1994	9720	7634	**17354**	6854	5503	**12357**
WPR-B	Papua New Guinea	1980	1992	1567	**3559**	1666	1299	**2966**
WPR-B	Philippines	1998	242181	163760	**405941**	202585	135794	**338379**
WPR-B	Taiwan	1969	38852	29367	**68219**	30331	22394	**52725**

WPR-B	**10**		**859401**	**659591**	**1518993**	**790134**	**609055**	**1399188**

[a] Mortality was extracted from the WHO mortality database and was adjusted for coverage
[b] Any mortality recorder under 'sex unspecified' was split evenly between male and female categories

Table D2 Cardiopulmonary disease (CPD) mortality adjusted for coverage, by subregion

WHO Subregion	Country	Year of Mortality Data Collection	Cardiopulmonary Disease Mortality for All Ages[a]			Cardiopulmonary Disease Mortality for Adults (20+)[a]		
			Male[b]	Female[b]	Total	Male[b]	Female[b]	Total
AFR-D	Cape Verde	1980	270	316	**586**	168	217	**385**
AFR-D	Mauritius	2005	2264	1813	**4077**	2233	1796	**4029**
AFR-D	Reunion	2005	803	709	**1512**	796	705	**1501**
AFR-D	Sao Tome and Principe	1987	142	133	**275**	80	88	**168**
AFR-D	Seychelles	2005	186	151	**337**	186	151	**337**
AFR-D	**5**		**3665**	**3122**	**6787**	**3463**	**2957**	**6420**
AFR-E	South Africa	2005	90363	99876	**190239**	86824	95896	**182720**
AFR-E	Zimbabwe	1990	6665	4928	**11592**	4922	3312	**8234**
AFR-E	**2**		**97027**	**104803**	**201831**	**91745**	**99208**	**190953**
AMR-A	Canada	2004	44043	44571	**88614**	43966	44515	**88481**
AMR-A	Cuba	2005	22366	20748	**43114**	22277	20681	**42958**
AMR-A	United States of America	2005	506367	563423	**1069790**	504638	562202	**1066840**
AMR-A	**3**		**572776**	**628742**	**1201518**	**570881**	**627398**	**1198279**
AMR-B	Anguilla	2005	6	7	**13**	6	7	**13**
AMR-B	Antigua and Barbuda	2004	113	116	**229**	110	116	**227**
AMR-B	Argentina	2005	64394	63656	**128050**	63615	62949	**126564**
AMR-B	Aruba	1999	116	106	**222**	116	105	**221**
AMR-B	Bahamas	2000	312	308	**620**	303	301	**604**
AMR-B	Barbados	2001	301	399	**700**	300	397	**698**
AMR-B	Belize	2001	255	208	**463**	238	193	**431**

AMR-B	Bermuda	2002	74	72	**146**	74	71	**145**
AMR-B	Brazil	2004	239341	210929	**450270**	234079	206516	**440595**
AMR-B	British Virgin Islands	2003	23	17	**40**	23	17	**40**
AMR-B	Cayman Islands	2004	31	36	**67**	31	36	**67**
AMR-B	Chile	2005	16696	16189	**32885**	16574	16069	**32643**
AMR-B	Colombia	2005	45808	42286	**88094**	44413	41063	**85476**
AMR-B	Costa Rica	2005	3516	2977	**6493**	3458	2920	**6378**
AMR-B	Dominica, Commonwealth of	2004	107	131	**238**	107	128	**235**
AMR-B	Dominican Republic	2004	9298	7660	**16958**	9039	7425	**16464**
AMR-B	El Salvador	2005	5093	5163	**10255**	4848	4981	**9829**
AMR-B	Falkland Islands	1983	6	3	**9**	6	3	**9**
AMR-B	French Guyana	2005	83	81	**164**	79	78	**157**
AMR-B	Grenada	2002	231	285	**516**	231	280	**511**
AMR-B	Guadeloupe	2005	464	473	**937**	462	471	**933**
AMR-B	Guyana	2005	1332	1210	**2542**	1302	1183	**2485**
AMR-B	Honduras	1990	2390	2181	**4571**	1953	1732	**3685**
AMR-B	Jamaica	1991	3145	3470	**6614**	3047	3383	**6430**
AMR-B	Martinique	2005	363	397	**760**	362	393	**755**
AMR-B	Mexico	2005	81319	76740	**158059**	78161	74230	**152391**
AMR-B	Montserrat	2003	13	9	**22**	13	9	**22**
AMR-B	Netherlands Antilles	1981	158	180	**338**	153	178	**331**
AMR-B	Panama	2004	2866	2264	**5130**	2770	2199	**4969**
AMR-B	Paraguay	2004	4379	3937	**8317**	4140	3690	**7830**
AMR-B	Puerto Rico	2005	5884	5200	**11084**	5846	5183	**11029**
AMR-B	Saint Kitts and Nevis	2005	58	92	**150**	58	92	**150**
AMR-B	Saint Lucia	2002	151	159	**310**	148	156	**303**
AMR-B	Saint Pierre and Miquelon	2005	7	12	**19**	7	12	**19**

AMR-B	Saınt Vıncent and Grenadınes	2003	157	168	**326**	157	167	**324**
AMR-B	Surıname	2000	653	495	**1148**	635	475	**1110**
AMR-B	Trınıdad and Tobago	2002	2436	2081	**4517**	2406	2050	**4456**
AMR-B	Turks and Caıcos Islands	2005	21	25	**46**	21	25	**46**
AMR-B	Uruguay	2004	6550	6754	**13305**	6507	6719	**13226**
AMR-B	Venezuela	2005	43871	36089	**79960**	42858	35268	**78126**
AMR-B	Vırgın Islands, U S	2005	141	138	**279**	141	137	**278**
AMR-B	**41**		**542161**	**492702**	**1034863**	**528798**	**481406**	**1010204**
AMR-D	Ecuador	2005	11453	10164	**21616**	10584	9439	**20023**
AMR-D	Guatamala	2004	11153	10151	**21304**	8067	7415	**15482**
AMR-D	Haıtı	2003	876	1168	**2044**	791	1059	**1850**
AMR-D	Nıcaragua	2005	3938	3739	**7677**	3677	3531	**7208**
AMR-D	Peru	2000	19036	17770	**36805**	17317	16297	**33614**
AMR-D	**5**		**46455**	**42991**	**89446**	**40435**	**37741**	**78176**
EMR-B	Bahraın	2001	468	277	**745**	459	269	**728**
EMR-B	Iran	1987	12535	9762	**22297**	9874	7565	**17439**
EMR-B	Kuwaıt	2002	1256	647	**1903**	1222	637	**1859**
EMR-B	Qatar	1995	299	153	**453**	294	148	**443**
EMR-B	Syrıa	1985	3156	2321	**5477**	2545	1764	**4309**
EMR-B	**5**		**17714**	**13160**	**30874**	**14394**	**10384**	**24777**
EMR-D	Egypt	2000	98802	84729	**183532**	81177	69480	**150657**
EMR-D	Pakıstan	1994	197	170	**367**	158	130	**288**
EMR-D	**2**		**98999**	**84899**	**183899**	**81335**	**69610**	**150945**
EUR-A	Austrıa	2005	14705	20953	**35658**	14696	20942	**35638**
EUR-A	Belgıum	1997	22326	24654	**46980**	22288	24635	**46923**
EUR-A	Croatıa	2005	13339	16382	**29721**	13320	16370	**29690**
EUR-A	Cyprus	2006	1247	1237	**2485**	1245	1235	**2480**
EUR-A	Czech Republıc	2005	27187	32677	**59864**	27159	32651	**59810**
EUR-A	Denmark	2001	12097	13322	**25419**	12089	13316	**25405**
EUR-A	Fınland	2005	10326	11060	**21386**	10320	11052	**21372**
EUR-A	France	2005	83143	92549	**175693**	83006	92432	**175438**

EUR-A	Germany	2005	174591	235201	**409792**	174411	235020	**409431**
EUR-A	Greece	2005	27485	29460	**56945**	27432	29441	**56873**
EUR-A	Iceland	2005	416	415	**832**	415	414	**830**
EUR-A	Ireland	2005	6644	6754	**13398**	6631	6744	**13375**
EUR-A	Israel	2004	6426	6744	**13170**	6382	6705	**13087**
EUR-A	Italy	2003	123565	149071	**272636**	123406	148963	**272369**
EUR-A	Luxembourg	2005	709	897	**1606**	709	897	**1606**
EUR-A	Malta	2005	858	851	**1709**	856	849	**1705**
EUR-A	Monaco	1987	126	141	**267**	125	141	**266**
EUR-A	Netherlands, Kingdom of the	2005	26615	28707	**55322**	26570	28670	**55240**
EUR-A	Norway	2005	8511	9412	**17923**	8501	9408	**17909**
EUR-A	Portugal	2003	23206	26321	**49527**	23162	26282	**49444**
EUR-A	San Marino	2005	62	61	**123**	62	60	**122**
EUR-A	Slovenia	2005	3928	4863	**8791**	3922	4859	**8781**
EUR-A	Spain	2005	81838	86443	**168281**	81732	86367	**168099**
EUR-A	Sweden	2005	20744	22325	**43069**	20712	22311	**43023**
EUR-A	Switzerland	2005	12072	14175	**26247**	12059	14169	**26228**
EUR-A	United Kingdom	2005	127889	144393	**272282**	127632	144234	**271866**
EUR-A	**26**		**830055**	**979070**	**1809125**	**828842**	**978168**	**1807010**
EUR-B	Albania	2004	6534	5755	**12288**	6310	5566	**11876**
EUR-B	Armenia	2003	10753	10809	**21562**	10687	10747	**21434**
EUR-B	Azerbaijan	2004	20095	20416	**40510**	19262	19663	**38925**
EUR-B	Bosnia and Herzegovina	1991	7885	7919	**15804**	7812	7874	**15686**
EUR-B	Bulgaria	2004	38981	37132	**76113**	38771	36989	**75760**
EUR-B	Georgia	2001	13862	15663	**29525**	13713	15558	**29271**
EUR-B	Kyrgyzstan	2005	12983	13034	**26016**	12352	12556	**24908**
EUR-B	Macedonia	2003	6078	5913	**11992**	6056	5899	**11955**
EUR-B	Poland	2005	88397	95168	**183565**	88236	95027	**183263**
EUR-B	Romania	2005	84367	89736	**174103**	83675	89192	**172867**
EUR-B	Serbia and Montenegro, Former	2002	34508	38631	**73138**	34461	38578	**73039**
EUR-B	Slovakia	2005	15139	16855	**31994**	15088	16821	**31909**

EUR-B	Tajikistan	2005	13020	12029	**25050**	12230	11368	**23598**
EUR-B	Turkey	1987	37769	31278	**69047**	33666	27852	**61519**
EUR-B	Turkmenistan	1998	8431	8562	**16993**	5942	6551	**12493**
EUR-B	Uzbekistan	2005	57439	56559	**113998**	53340	53208	**106548**
EUR-B	**16**		**456241**	**465458**	**921699**	**441601**	**453449**	**895050**
EUR-C	Belarus	2003	41707	41720	**83427**	41647	41694	**83341**
EUR-C	Estonia	2005	4309	5202	**9511**	4302	5200	**9502**
EUR-C	Hungary	2005	35549	40343	**75892**	35496	40304	**75800**
EUR-C	Kazakhstan	2005	54021	52113	**106134**	53291	51542	**104833**
EUR-C	Latvia	2005	9110	10501	**19611**	9099	10493	**19591**
EUR-C	Lithuania	2005	11977	13721	**25698**	11958	13707	**25665**
EUR-C	Moldova	2005	15221	17112	**32334**	15138	17048	**32187**
EUR-C	Russia	2005	662410	715904	**1378314**	660504	714688	**1375192**
EUR-C	Ukraine	2005	234965	275329	**510294**	234559	275072	**509631**
EUR-C	**9**		**1069270**	**1171945**	**2241215**	**1065995**	**1169748**	**2235743**
SEAR-B	Sri Lanka	1995	20939	12034	**32973**	20022	11434	**31456**
SEAR-B	Thailand	2002	39236	26398	**65635**	37518	25083	**62600**
SEAR-B	**2**		**60176**	**38432**	**98608**	**57540**	**36517**	**94057**
SEAR-D	Maldives	2005	92	65	**156**	90	62	**152**
SEAR-D	**1**		**92**	**65**	**156**	**90**	**62**	**152**
WPR-A	Australia	2003	28072	29663	**57735**	27984	29606	**57590**
WPR-A	Brunei	2000	218	127	**345**	214	124	**338**
WPR-A	Japan	2005	242563	236061	**478624**	242027	235673	**477700**
WPR-A	New Zealand	2004	6289	6901	**13190**	6265	6886	**13151**
WPR-A	Singapore	2005	5368	4454	**9821**	5337	4433	**9770**
WPR-A	**5**		**282510**	**277206**	**559715**	**281827**	**276722**	**558549**
WPR-B	China	2000	202755	179863	**382618**	200554	177974	**378528**
WPR-B	Fiji	1999	1034	635	**1669**	960	585	**1545**
WPR-B	Hong Kong	2005	8898	7704	**16602**	8871	7679	**16550**
WPR-B	Kiribati	2001	97	48	**145**	83	25	**107**
WPR-B	Korea; Republic of (south)	2005	38185	37503	**75688**	38030	37390	**75419**
WPR-B	Macao	1994	330	310	**640**	325	308	**633**
WPR-B	Mongolia	1994	3908	3549	**7458**	2658	2617	**5275**

WPR-B	Papua New Guinea	1980	710	591	**1301**	650	539	**1189**
WPR-B	Philippines	1998	98210	74015	**172225**	89948	67528	**157476**
WPR-B	Taiwan	1969	6970	6391	**13361**	5075	4487	**9562**
WPR-B	**10**		**361098**	**310609**	**671707**	**347154**	**299132**	**646285**

[a] Mortality was extracted from the WHO mortality database and was adjusted for coverage
[b] Any mortality recorder under 'sex unspecified' was split evenly between male and female categories

Table D3 Lung cancer (LC) mortality adjusted for coverage, by subregion

WHO Subregion	Country	Year of Mortality Data Collection	Lung Cancer Mortality for All Ages[a]			Lung Cancer Mortality for Adults (20+)[a]		
			Male[b]	Female[b]	Total	Male[b]	Female[b]	Total
AFR-D	Cape Verde	1980	6	4	**10**	6	4	**10**
AFR-D	Mauritius	2005	76	39	**115**	76	39	**115**
AFR-D	Reunion	2005	121	19	**140**	121	19	**140**
AFR-D	Sao Tome and Principe	1987	2	1	**3**	2	1	**3**
AFR-D	Seychelles	2005	8	3	**11**	8	3	**11**
AFR-D	**5**		**213**	**66**	**279**	**213**	**66**	**279**
AFR-E	South Africa	2005	3902	1786	**5687**	3898	1783	**5681**
AFR-E	Zimbabwe	1990	287	75	**362**	287	75	**362**
AFR-E	**2**		**4188**	**1861**	**6049**	**4184**	**1858**	**6043**
AMR-A	Canada	2004	10136	7517	**17653**	10135	7517	**17652**
AMR-A	Cuba	2005	2991	1493	**4484**	2991	1493	**4484**
AMR-A	United States of America	2005	90277	69174	**159451**	90270	69174	**159444**
AMR-A	**3**		**103404**	**78184**	**181588**	**103396**	**78184**	**181580**
AMR-B	Anguilla	2005	0	1	**1**	0	1	**1**
AMR-B	Antigua and Barbuda	2004	1	1	**2**	1	1	**2**
AMR-B	Argentina	2005	6393	2104	**8496**	6387	2103	**8489**
AMR-B	Aruba	1999	9	2	**11**	9	2	**11**
AMR-B	Bahamas	2000	16	11	**27**	16	11	**27**

AMR-B	Barbados	2001	12	3	**15**	12	3	**15**
AMR-B	Belize	2001	14	3	**17**	14	3	**17**
AMR-B	Bermuda	2002	13	6	**19**	13	6	**19**
AMR-B	Brazil	2004	14114	6929	**21043**	14103	6912	**21015**
AMR-B	British Virgin Islands	2003	0	0	**0**	0	0	**0**
AMR-B	Cayman Islands	2004	7	2	**9**	7	2	**9**
AMR-B	Chile	2005	1559	864	**2423**	1558	864	**2422**
AMR-B	Colombia	2005	2728	1741	**4470**	2704	1723	**4427**
AMR-B	Costa Rica	2005	186	102	**288**	186	102	**288**
AMR-B	Dominica, Commonwealth of	2004	4	1	**5**	4	1	**5**
AMR-B	Dominican Republic	2004	387	231	**618**	387	231	**618**
AMR-B	El Salvador	2005	139	140	**279**	139	140	**279**
AMR-B	Falkland Islands	1983	1	0	**1**	1	0	**1**
AMR-B	French Guyana	2005	8	1	**9**	8	1	**9**
AMR-B	Grenada	2002	8	1	**9**	8	1	**9**
AMR-B	Guadeloupe	2005	45	14	**59**	45	14	**59**
AMR-B	Guyana	2005	30	5	**35**	30	5	**35**
AMR-B	Honduras	1990	22	9	**31**	21	9	**30**
AMR-B	Jamaica	1991	264	88	**353**	264	88	**353**
AMR-B	Martinique	2005	31	14	**45**	31	14	**45**
AMR-B	Mexico	2005	5016	2325	**7341**	5004	2314	**7318**
AMR-B	Montserrat	2003	0	0	**0**	0	0	**0**
AMR-B	Netherlands Antilles	1981	21	3	**24**	21	3	**24**
AMR-B	Panama	2004	170	87	**257**	170	87	**257**
AMR-B	Paraguay	2004	311	83	**395**	310	83	**393**
AMR-B	Puerto Rico	2005	336	209	**545**	336	209	**545**
AMR-B	Saint Kitts and Nevis	2005	1	0	**1**	1	0	**1**
AMR-B	Saint Lucia	2002	4	3	**7**	4	3	**7**

AMR-B	Saint Pierre and Miquelon	2005	1	1	**2**	1	1	**2**
AMR-B	Saint Vincent and Grenadines	2003	8	5	**13**	8	5	**13**
AMR-B	Suriname	2000	38	12	**49**	38	12	**49**
AMR-B	Trinidad and Tobago	2002	91	30	**121**	91	30	**121**
AMR-B	Turks and Caicos Islands	2005	0	0	**0**	0	0	**0**
AMR-B	Uruguay	2004	933	201	**1134**	933	201	**1134**
AMR-B	Venezuela	2005	3127	1940	**5067**	3114	1936	**5050**
AMR-B	Virgin Islands; U.S.	2005	6	2	**8**	6	2	**8**
AMR-B	**41**		**36054**	**17174**	**53228**	**35985**	**17123**	**53108**
AMR-D	Ecuador	2005	456	303	**759**	449	303	**751**
AMR-D	Guatamala	2004	244	195	**439**	233	191	**424**
AMR-D	Haiti	2003	11	12	**24**	11	12	**24**
AMR-D	Nicaragua	2005	112	89	**201**	112	89	**201**
AMR-D	Peru	2000	973	648	**1620**	964	646	**1610**
AMR-D	**5**		**1796**	**1246**	**3042**	**1768**	**1242**	**3010**
EMR-B	Bahrain	2001	48	9	**57**	48	9	**57**
EMR-B	Iran	1987	420	230	**650**	420	226	**646**
EMR-B	Kuwait	2002	50	11	**61**	48	11	**59**
EMR-B	Qatar	1995	18	4	**22**	18	4	**22**
EMR-B	Syria	1985	51	13	**64**	51	13	**64**
EMR-B	**5**		**587**	**267**	**854**	**585**	**262**	**848**
EMR-D	Egypt	2000	1164	458	**1622**	1132	441	**1573**
EMR-D	Pakistan	1994	0	0	**0**	0	0	**0**
EMR-D	**2**		**1164**	**458**	**1622**	**1132**	**441**	**1573**
EUR-A	Austria	2005	2317	1031	**3348**	2317	1030	**3347**
EUR-A	Belgium	1997	5723	1090	**6813**	5723	1090	**6813**
EUR-A	Croatia	2005	2153	572	**2724**	2153	572	**2724**
EUR-A	Cyprus	2006	130	37	**167**	130	37	**167**
EUR-A	Czech Republic	2005	4170	1373	**5543**	4170	1372	**5542**
EUR-A	Denmark	2001	1957	1486	**3443**	1957	1486	**3443**

EUR-A	Finland	2005	1413	536	**1949**	1413	535	**1948**
EUR-A	France	2005	22295	6056	**28351**	22294	6055	**28349**
EUR-A	Germany	2005	28980	11701	**40681**	28975	11699	**40674**
EUR-A	Greece	2005	5063	925	**5988**	5063	925	**5988**
EUR-A	Iceland	2005	75	58	**133**	75	58	**133**
EUR-A	Ireland	2005	932	641	**1574**	932	641	**1574**
EUR-A	Israel	2004	1024	444	**1468**	1021	444	**1465**
EUR-A	Italy	2003	25833	6431	**32264**	25832	6428	**32260**
EUR-A	Luxembourg	2005	144	62	**206**	144	62	**206**
EUR-A	Malta	2005	109	18	**127**	109	18	**127**
EUR-A	Monaco	1987	25	9	**34**	25	9	**34**
EUR-A	Netherlands, Kingdom of the	2005	6359	3055	**9414**	6359	3055	**9414**
EUR-A	Norway	2005	1186	781	**1967**	1186	781	**1967**
EUR-A	Portugal	2003	2583	578	**3161**	2583	577	**3160**
EUR-A	San Marino	2005	14	8	**23**	14	8	**23**
EUR-A	Slovenia	2005	805	274	**1079**	805	274	**1079**
EUR-A	Spain	2005	16647	2471	**19118**	16644	2471	**19115**
EUR-A	Sweden	2005	1938	1567	**3505**	1937	1567	**3504**
EUR-A	Switzerland	2005	2062	847	**2909**	2062	847	**2909**
EUR-A	United Kingdom	2005	19475	14028	**33503**	19475	14028	**33503**
EUR-A	**26**		**153413**	**56078**	**209492**	**153399**	**56068**	**209468**
EUR-B	Albania	2004	599	182	**782**	596	180	**775**
EUR-B	Armenia	2003	1048	182	**1230**	1047	182	**1229**
EUR-B	Azerbaijan	2004	903	241	**1143**	895	237	**1132**
EUR-B	Bosnia and Herzegovina	1991	1206	234	**1440**	1204	234	**1438**
EUR-B	Bulgaria	2004	2611	548	**3159**	2611	547	**3158**
EUR-B	Georgia	2001	670	169	**838**	670	169	**838**
EUR-B	Kyrgyzstan	2005	384	108	**492**	381	107	**487**
EUR-B	Macedonia	2003	615	95	**710**	615	95	**710**
EUR-B	Poland	2005	16612	4968	**21580**	16612	4967	**21579**
EUR-B	Romania	2005	7323	1712	**9035**	7321	1711	**9032**

EUR-B	Serbia and Montenegro, Former	2002	4051	1136	**5187**	4051	1136	**5187**
EUR-B	Slovakia	2005	1741	380	**2120**	1741	380	**2120**
EUR-B	Tajikistan	2005	164	89	**253**	158	86	**244**
EUR-B	Turkey	1987	3192	668	**3860**	3176	657	**3833**
EUR-B	Turkmenistan	1998	187	57	**244**	185	56	**241**
EUR-B	Uzbekistan	2005	960	358	**1318**	947	351	**1298**
EUR-B	**16**		**42265**	**11126**	**53391**	**42207**	**11094**	**53301**
EUR-C	Belarus	2003	3236	368	**3604**	3236	368	**3604**
EUR-C	Estonia	2005	500	140	**640**	500	140	**640**
EUR-C	Hungary	2005	5336	2235	**7571**	5336	2234	**7570**
EUR-C	Kazakhstan	2005	3380	765	**4145**	3376	765	**4142**
EUR-C	Latvia	2005	901	216	**1117**	901	216	**1117**
EUR-C	Lithuania	2005	1184	230	**1415**	1184	230	**1415**
EUR-C	Moldova	2005	770	179	**948**	769	179	**947**
EUR-C	Russia	2005	44432	8355	**52787**	44425	8347	**52772**
EUR-C	Ukraine	2005	13427	2420	**15847**	13424	2417	**15841**
EUR-C	**9**		**73166**	**14908**	**88074**	**73151**	**14896**	**88047**
SEAR-B	Sri Lanka	1995	345	149	**494**	344	149	**492**
SEAR-B	Thailand	2002	5409	2485	**7895**	5389	2475	**7864**
SEAR-B	**2**		**5754**	**2635**	**8389**	**5732**	**2624**	**8356**
SEAR-D	Maldives	2005	3	5	**8**	3	5	**8**
SEAR-D	**1**		**3**	**5**	**8**	**3**	**5**	**8**
WPR-A	Australia	2003	4505	2481	**6986**	4503	2481	**6984**
WPR-A	Brunei	2000	19	17	**36**	19	17	**36**
WPR-A	Japan	2005	45189	16874	**62063**	45187	16873	**62060**
WPR-A	New Zealand	2004	929	626	**1555**	929	626	**1555**
WPR-A	Singapore	2005	839	381	**1220**	839	381	**1220**
WPR-A	**5**		**51481**	**20379**	**71860**	**51477**	**20378**	**71855**
WPR-B	China	2000	25892	12403	**38295**	25868	12393	**38261**
WPR-B	Fiji	1999	27	10	**38**	26	10	**37**
WPR-B	Hong Kong	2005	2503	1183	**3686**	2503	1183	**3686**
WPR-B	Kiribati	2001	1	1	**3**	1	1	**3**

WPR-B	Korea, Republic of (south)	2005	11037	3969	**15006**	11037	3969	**15006**
WPR-B	Macao	1994	47	42	**89**	47	42	**89**
WPR-B	Mongolia	1994	258	82	**340**	255	82	**337**
WPR-B	Papua New Guinea	1980	8	2	**10**	8	2	**10**
WPR-B	Philippines	1998	4773	1557	**6330**	4745	1547	**6292**
WPR-B	Taiwan	1969	485	241	**726**	479	239	**718**
WPR-B	**10**		**45032**	**19491**	**64523**	**44969**	**19468**	**64438**

[a] Mortality was extracted from the WHO mortality database and was adjusted for coverage
[b] Any mortality recorder under 'sex unspecified' was split evenly between male and female categories

Table D4 Ischemic heart disease (IHD) mortality adjusted for coverage, by subregion

WHO Subregion	Country	Year of Mortality Data Collection	Ischemic Heart Disease Mortality for All Ages[a]			Ischemic Heart Disease Mortality for Adults (20+)[a]		
			Male[b]	Female[b]	Total	Male[b]	Female[b]	Total
AFR-D	Cape Verde	1980	12	9	**21**	11	8	**19**
AFR-D	Mauritius	2005	739	549	**1288**	739	549	**1288**
AFR-D	Reunion	2005	184	134	**318**	184	134	**318**
AFR-D	Sao Tome and Principe	1987	0	3	**3**	0	3	**3**
AFR-D	Seychelles	2005	39	18	**57**	39	18	**57**
AFR-D	**5**		**974**	**713**	**1687**	**973**	**712**	**1685**
AFR-E	South Africa	2005	9115	6779	**15893**	9094	6749	**15843**
AFR-E	Zimbabwe	1990	314	189	**503**	312	186	**498**
AFR-E	**2**		**9428**	**6968**	**16396**	**9406**	**6935**	**16341**
AMR-A	Canada	2004	21578	17740	**39318**	21569	17740	**39309**
AMR-A	Cuba	2005	8740	7647	**16387**	8739	7646	**16385**
AMR-A	United States of America	2005	232347	213786	**446133**	232304	213766	**446070**
AMR-A	**3**		**262665**	**239173**	**501838**	**262612**	**239152**	**501764**
AMR-B	Anguilla	2005	3	1	**4**	3	1	**4**

AMR-B	Antigua and Barbuda	2004	33	26	**59**	32	26	**58**
AMR-B	Argentina	2005	11708	7779	**19486**	11702	7771	**19472**
AMR-B	Aruba	1999	36	31	**67**	36	31	**67**
AMR-B	Bahamas	2000	115	98	**213**	115	96	**212**
AMR-B	Barbados	2001	70	69	**139**	70	69	**139**
AMR-B	Belize	2001	44	34	**78**	44	34	**78**
AMR-B	Bermuda	2002	27	21	**48**	27	21	**48**
AMR-B	Brazil	2004	60279	44131	**104410**	60222	44106	**104328**
AMR-B	British Virgin Islands	2003	7	1	**8**	7	1	**8**
AMR-B	Cayman Islands	2004	9	5	**14**	9	5	**14**
AMR-B	Chile	2005	4968	3417	**8385**	4966	3417	**8383**
AMR-B	Colombia	2005	17902	13945	**31847**	17873	13927	**31800**
AMR-B	Costa Rica	2005	1450	1021	**2470**	1450	1021	**2470**
AMR-B	Dominica, Commonwealth of	2004	19	11	**30**	19	11	**30**
AMR-B	Dominican Republic	2004	2995	2261	**5256**	2979	2250	**5229**
AMR-B	El Salvador	2005	1368	1265	**2633**	1361	1259	**2620**
AMR-B	Falkland Islands	1983	2	0	**2**	2	0	**2**
AMR-B	French Guyana	2005	13	6	**19**	13	6	**19**
AMR-B	Grenada	2002	26	30	**56**	26	30	**56**
AMR-B	Guadeloupe	2005	56	44	**100**	56	44	**100**
AMR-B	Guyana	2005	473	353	**826**	473	353	**826**
AMR-B	Honduras	1990	148	97	**245**	143	93	**236**
AMR-B	Jamaica	1991	385	427	**811**	383	425	**809**
AMR-B	Martinique	2005	52	39	**91**	52	39	**91**
AMR-B	Mexico	2005	31044	24591	**55635**	30984	24571	**55555**
AMR-B	Montserrat	2003	2	0	**2**	2	0	**2**
AMR-B	Netherlands Antilles	1981	37	25	**62**	37	25	**62**
AMR-B	Panama	2004	875	621	**1496**	875	621	**1496**
AMR-B	Paraguay	2004	1158	759	**1917**	1152	758	**1910**

AMR-B	Puerto Rico	2005	2444	1826	**4270**	2444	1826	**4270**
AMR-B	Saint Kitts and Nevis	2005	25	19	**44**	25	19	**44**
AMR-B	Saint Lucia	2002	18	27	**45**	18	27	**45**
AMR-B	Saint Pierre and Miquelon	2005	3	5	**8**	3	5	**8**
AMR-B	Saint Vincent and Grenadines	2003	31	38	**69**	31	38	**69**
AMR-B	Suriname	2000	148	100	**248**	148	100	**248**
AMR-B	Trinidad and Tobago	2002	1127	835	**1963**	1125	830	**1955**
AMR-B	Turks and Caicos Islands	2005	0	0	**0**	0	0	**0**
AMR-B	Uruguay	2004	1597	1219	**2816**	1596	1218	**2814**
AMR-B	Venezuela	2005	20300	13501	**33801**	20271	13481	**33752**
AMR-B	Virgin Islands, U.S.	2005	72	78	**150**	72	78	**150**
AMR-B	**41**		**161070**	**118754**	**279824**	**160848**	**118631**	**279479**
AMR-D	Ecuador	2005	1934	1200	**3134**	1928	1191	**3119**
AMR-D	Guatamala	2004	1202	987	**2189**	1183	955	**2138**
AMR-D	Haiti	2003	50	63	**113**	49	63	**112**
AMR-D	Nicaragua	2005	1430	1369	**2799**	1420	1368	**2788**
AMR-D	Peru	2000	2921	2087	**5008**	2910	2078	**4988**
AMR-D	**5**		**7537**	**5706**	**13243**	**7489**	**5655**	**13144**
EMR-B	Bahrain	2001	127	51	**178**	127	51	**178**
EMR-B	Iran	1987	1316	826	**2142**	1235	760	**1995**
EMR-B	Kuwait	2002	543	151	**694**	541	151	**692**
EMR-B	Qatar	1995	158	49	**207**	158	49	**207**
EMR-B	Syria	1985	1513	838	**2351**	1337	720	**2057**
EMR-B	**5**		**3657**	**1915**	**5573**	**3398**	**1731**	**5129**
EMR-D	Egypt	2000	6686	4840	**11526**	6506	4674	**11180**
EMR-D	Pakistan	1994	87	50	**137**	82	47	**129**
EMR-D	**2**		**6773**	**4890**	**11663**	**6588**	**4721**	**11309**
EUR-A	Austria	2005	6723	8221	**14944**	6723	8221	**14944**
EUR-A	Belgium	1997	6723	5256	**11979**	6722	5256	**11978**

EUR-A	Croatia	2005	4973	5293	**10266**	4973	5293	**10266**
EUR-A	Cyprus	2006	463	277	**740**	462	277	**739**
EUR-A	Czech Republic	2005	11330	12037	**23367**	11330	12037	**23367**
EUR-A	Denmark	2001	4832	4434	**9266**	4832	4434	**9266**
EUR-A	Finland	2005	5916	5812	**11728**	5916	5811	**11727**
EUR-A	France	2005	23399	17929	**41328**	23398	17925	**41323**
EUR-A	Germany	2005	72003	76638	**148641**	71993	76638	**148631**
EUR-A	Greece	2005	7997	4732	**12729**	7996	4732	**12728**
EUR-A	Iceland	2005	198	147	**345**	198	147	**345**
EUR-A	Ireland	2005	2859	2241	**5099**	2859	2241	**5099**
EUR-A	Israel	2004	2550	2187	**4737**	2548	2186	**4734**
EUR-A	Italy	2003	41458	40601	**82059**	41452	40598	**82050**
EUR-A	Luxembourg	2005	216	184	**400**	216	184	**400**
EUR-A	Malta	2005	429	361	**790**	429	361	**790**
EUR-A	Monaco	1987	23	6	**29**	23	6	**29**
EUR-A	Netherlands, Kingdom of the	2005	7631	5712	**13343**	7629	5712	**13341**
EUR-A	Norway	2005	3302	2769	**6071**	3301	2769	**6070**
EUR-A	Portugal	2003	5077	4547	**9624**	5074	4546	**9620**
EUR-A	San Marino	2005	7	4	**11**	7	4	**11**
EUR-A	Slovenia	2005	1128	1010	**2138**	1128	1010	**2138**
EUR-A	Spain	2005	22188	17125	**39313**	22183	17124	**39307**
EUR-A	Sweden	2005	9678	8031	**17709**	9677	8031	**17708**
EUR-A	Switzerland	2005	4821	4541	**9362**	4821	4541	**9362**
EUR-A	United Kingdom	2005	56337	44876	**101213**	56334	44872	**101206**
EUR-A	**26**		**302262**	**274970**	**577232**	**302225**	**274955**	**577180**
EUR-B	Albania	2004	2058	1376	**3434**	2040	1353	**3393**
EUR-B	Armenia	2003	6095	5724	**11819**	6091	5723	**11814**
EUR-B	Azerbaijan	2004	9286	7023	**16309**	9275	7014	**16289**
EUR-B	Bosnia and Herzegovina	1991	2006	1181	**3187**	2003	1181	**3184**
EUR-B	Bulgaria	2004	10111	8267	**18378**	10110	8265	**18375**
EUR-B	Georgia	2001	7638	8289	**15927**	7638	8289	**15927**
EUR-B	Kyrgyzstan	2005	5710	6043	**11753**	5710	6041	**11751**
EUR-B	Macedonia	2003	1418	871	**2289**	1418	870	**2288**

EUR-B	Poland	2005	27097	22825	**49922**	27095	22825	**49920**
EUR-B	Romania	2005	28012	26633	**54645**	28008	26632	**54640**
EUR-B	Serbia and Montenegro, Former	2002	8044	6664	**14708**	8043	6664	**14707**
EUR-B	Slovakia	2005	7170	8324	**15494**	7170	8324	**15494**
EUR-B	Tajikistan	2005	4747	3544	**8291**	4747	3541	**8288**
EUR-B	Turkey	1987	920	338	**1258**	920	338	**1258**
EUR-B	Turkmenistan	1998	4524	4026	**8550**	4516	4020	**8536**
EUR-B	Uzbekistan	2005	25935	24370	**50305**	25934	24368	**50301**
EUR-B	**16**		**150772**	**135498**	**286270**	**150718**	**135447**	**286165**
EUR-C	Belarus	2003	26273	26359	**52632**	26271	26359	**52630**
EUR-C	Estonia	2005	2268	2644	**4912**	2268	2644	**4912**
EUR-C	Hungary	2005	17559	19334	**36893**	17557	19334	**36891**
EUR-C	Kazakhstan	2005	22863	20736	**43599**	22847	20730	**43577**
EUR-C	Latvia	2005	4614	4784	**9398**	4614	4784	**9398**
EUR-C	Lithuania	2005	7145	8326	**15470**	7145	8326	**15470**
EUR-C	Moldova	2005	8821	10797	**19618**	8816	10795	**19611**
EUR-C	Russia	2005	312759	312785	**625544**	312681	312757	**625438**
EUR-C	Ukraine	2005	147845	178397	**326242**	147824	178385	**326209**
EUR-C	**9**		**550147**	**584162**	**1134309**	**550024**	**584114**	**1134138**
SEAR-B	Sri Lanka	1995	3667	1787	**5454**	3649	1779	**5429**
SEAR-B	Thailand	2002	6083	4261	**10345**	6055	4243	**10298**
SEAR-B	**2**		**9750**	**6048**	**15798**	**9704**	**6022**	**15726**
SEAR-D	Maldives	2005	15	5	**20**	15	5	**20**
SEAR-D	**1**		**15**	**5**	**20**	**15**	**5**	**20**
WPR-A	Australia	2003	13440	11855	**25295**	13437	11854	**25291**
WPR-A	Brunei	2000	47	18	**65**	47	18	**65**
WPR-A	Japan	2005	41970	34533	**76503**	41955	34528	**76483**
WPR-A	New Zealand	2004	3368	2949	**6317**	3368	2949	**6317**
WPR-A	Singapore	2005	2000	1450	**3450**	2000	1450	**3450**
WPR-A	**5**		**60825**	**50805**	**111630**	**60807**	**50799**	**111606**
WPR-B	China	2000	33147	29531	**62678**	33121	29514	**62635**
WPR-B	Fiji	1999	445	104	**550**	438	104	**542**
WPR-B	Hong Kong	2005	2176	1827	**4003**	2176	1827	**4003**

WPR-B	Kiribati	2001	1	0	**1**	0	1	**1**
WPR-B	Korea, Republic of (south)	2005	7649	6927	**14577**	7646	6925	**14571**
WPR-B	Macao	1994	81	78	**159**	81	78	**159**
WPR-B	Mongolia	1994	761	579	**1340**	761	572	**1333**
WPR-B	Papua New Guinea	1980	3	1	**4**	3	1	**4**
WPR-B	Philippines	1998	21197	13130	**34326**	21070	13051	**34122**
WPR-B	Taiwan	1969	783	758	**1541**	775	753	**1528**
WPR-B	**10**		**66243**	**52935**	**119179**	**66071**	**52827**	**118898**

[a] Mortality was extracted from the WHO mortality database and was adjusted for coverage

[b] Any mortality recorder under 'sex unspecified' was split evenly between male and female categories

APPENDIX E: The proportion of country-level all cause mortality that is due to cardiopulmonary disease, a comparison with the Unites States

WHO Subregion	Country	Percentage of Countries with Proportions Similar to the U.S.[b]		
		All Ages	Adults	
AFR-D	Cape Verde	0.26	0.32	N
AFR-D	Mauritius	0.46	0.48	Y
AFR-D	Reunion	0.35	0.36	Y
AFR-D	Sao Tome and Principe	0.27	0.32	N
AFR-D	Seychelles	0.50	0.52	Y
AFR-D	**5**			**60.0%**
AFR-E	South Africa	0.26	0.29	N
AFR-E	Zimbabwe	0.22	0.24	N
AFR-E	**2**			**0.0%**
AMR-A	Canada	0.39	0.40	Y
AMR-A	Cuba	0.51	0.52	Y
AMR-A	**United States of America**	**0.44**	**0.45**	**Y**
AMR-A	**3**			**100.0%**
AMR-B	Anguilla	0.23	0.24	N
AMR-B	Antigua and Barbuda	0.37	0.40	Y
AMR-B	Argentina	0.44	0.46	Y
AMR-B	Aruba	0.40	0.42	Y
AMR-B	Bahamas	0.32	0.34	N
AMR-B	Barbados	0.38	0.39	Y
AMR-B	Belize	0.32	0.36	Y
AMR-B	Bermuda	0.35	0.35	Y
AMR-B	Brazil	0.37	0.39	Y
AMR-B	British Virgin Islands	0.38	0.40	Y
AMR-B	Cayman Islands	0.41	0.43	Y
AMR-B	Chile	0.36	0.37	Y
AMR-B	Colombia	0.39	0.42	Y
AMR-B	Costa Rica	0.37	0.39	Y

AMR-B	Dominica, Commonwealth of	0.43	0.44	Y
AMR-B	Dominican Republic	0.37	0.41	Y
AMR-B	El Salvador	0.27	0.28	N
AMR-B	Falkland Islands	0.50	0.56	Y
AMR-B	French Guyana	0.22	0.26	N
AMR-B	Grenada	0.46	0.49	Y
AMR-B	Guadeloupe	0.32	0.33	Y
AMR-B	Guyana	0.38	0.41	Y
AMR-B	Honduras	0.27	0.30	N
AMR-B	Jamaica	0.42	0.44	Y
AMR-B	Martinique	0.29	0.30	N
AMR-B	Mexico	0.31	0.33	Y
AMR-B	Montserrat	0.40	0.40	Y
AMR-B	Netherlands Antilles	0.38	0.43	Y
AMR-B	Panama	0.35	0.38	Y
AMR-B	Paraguay	0.31	0.34	Y
AMR-B	Puerto Rico	0.38	0.38	Y
AMR-B	Saint Kitts and Nevis	0.42	0.44	Y
AMR-B	Saint Lucia	0.32	0.34	Y
AMR-B	Saint Pierre and Miquelon	0.36	0.36	Y
AMR-B	Saint Vincent and Grenadines	0.39	0.42	Y
AMR-B	Suriname	0.34	0.38	Y
AMR-B	Trinidad and Tobago	0.41	0.43	Y
AMR-B	Turks and Caicos Islands	0.87	0.92	N
AMR-B	Uruguay	0.41	0.42	Y
AMR-B	Venezuela	0.36	0.40	Y
AMR-B	Virgin Islands; U.S.	0.42	0.44	Y
AMR-B	**41**			**82.9%**
AMR-D	Ecuador	0.30	0.33	Y
AMR-D	Guatamala	0.29	0.29	N
AMR-D	Haiti	0.23	0.26	N
AMR-D	Nicaragua	0.32	0.38	Y

AMR-D	Peru	0.30	0.33	Y
AMR-D	**5**			**60.0%**
EMR-B	Bahrain	0.33	0.36	Y
EMR-B	Iran	0.28	0.32	N
EMR-B	Kuwait	0.44	0.51	Y
EMR-B	Qatar	0.37	0.44	Y
EMR-B	Syria	0.14	0.19	N
EMR-B	**5**			**60.0%**
EMR-D	Egypt	0.40	0.41	Y
EMR-D	Pakistan	0.22	0.38	Y
EMR-D	**2**			**100.0%**
EUR-A	Austria	0.47	0.48	Y
EUR-A	Belgium	0.45	0.46	Y
EUR-A	Croatia	0.56	0.56	Y
EUR-A	Cyprus	0.45	0.46	Y
EUR-A	Czech Republic	0.55	0.56	Y
EUR-A	Denmark	0.44	0.45	Y
EUR-A	Finland	0.45	0.45	Y
EUR-A	France	0.33	0.33	Y
EUR-A	Germany	0.49	0.50	Y
EUR-A	Greece	0.54	0.55	Y
EUR-A	Iceland	0.44	0.45	Y
EUR-A	Ireland	0.48	0.49	Y
EUR-A	Israel	0.35	0.36	Y
EUR-A	Italy	0.46	0.47	Y
EUR-A	Luxembourg	0.45	0.45	Y
EUR-A	Malta	0.53	0.53	Y
EUR-A	Monaco	0.53	0.53	Y
EUR-A	Netherlands; Kingdom of the	0.41	0.41	Y
EUR-A	Norway	0.44	0.44	Y
EUR-A	Portugal	0.45	0.46	Y
EUR-A	San Marino	0.47	0.47	Y
EUR-A	Slovenia	0.47	0.47	Y
EUR-A	Spain	0.43	0.44	Y
EUR-A	Sweden	0.47	0.47	Y
EUR-A	Switzerland	0.43	0.43	Y
EUR-A	United Kingdom	0.47	0.47	Y
EUR-A	**26**			**100.0%**
EUR-B	Albania	0.54	0.55	Y
EUR-B	Armenia	0.60	0.61	N
EUR-B	Azerbaijan	0.63	0.65	N

EUR-B	Bosnia and Herzegovina	0.52	0.54	Y
EUR-B	Bulgaria	0.69	0.70	N
EUR-B	Georgia	0.74	0.75	N
EUR-B	Kyrgyzstan	0.57	0.62	N
EUR-B	Macedonia	0.60	0.62	N
EUR-B	Poland	0.50	0.50	Y
EUR-B	Romania	0.66	0.67	N
EUR-B	Serbia and Montenegro, Former	0.58	0.58	N
EUR-B	Slovakia	0.59	0.60	N
EUR-B	Tajikistan	0.60	0.65	N
EUR-B	Turkey	0.52	0.59	Y
EUR-B	Turkmenistan	0.46	0.45	Y
EUR-B	Uzbekistan	0.64	0.67	N
EUR-B	**16**			**31.3%**
EUR-C	Belarus	0.58	0.58	Y
EUR-C	Estonia	0.55	0.56	Y
EUR-C	Hungary	0.56	0.56	Y
EUR-C	Kazakhstan	0.56	0.59	N
EUR-C	Latvia	0.57	0.58	Y
EUR-C	Lithuania	0.57	0.58	Y
EUR-C	Moldova	0.62	0.63	N
EUR-C	Russia	0.60	0.61	N
EUR-C	Ukraine	0.65	0.66	N
EUR-C	**9**			**60.0%**
SEAR-B	Sri Lanka	0.25	0.26	N
SEAR-B	Thailand	0.15	0.15	N
SEAR-B	**2**			**0.0%**
SEAR-D	Maldives	0.10	0.11	N
SEAR-D	**1**			**0.0%**
WPR-A	Australia	0.44	0.45	Y
WPR-A	Brunei	0.36	0.40	Y
WPR-A	Japan	0.44	0.44	Y
WPR-A	New Zealand	0.46	0.47	Y
WPR-A	Singapore	0.52	0.53	Y
WPR-A	**5**			**100.0%**
WPR-B	China	0.54	0.55	Y
WPR-B	Fiji	0.38	0.40	Y
WPR-B	Hong Kong	0.43	0.43	Y
WPR-B	Kiribati	0.22	0.26	N
WPR-B	Korea; Republic of (south)	0.28	0.29	N

WPR-B	Macao	0.48	0.50	Y
WPR-B	Mongolia	0.43	0.43	Y
WPR-B	Papua New Guinea	0.37	0.40	Y
WPR-B	Philippines	0.42	0.47	Y
WPR-B	Taiwan	0.20	0.18	N
WPR-B	**10**			**70.0%**

[a] Mortality was extracted from the WHO mortality database and was adjusted for coverage

[b] Proportions were considered to be similar to those of the U.S. if they were within a 10 percent range on average across the two age categories; dissimilar proportions are highlighted

APPENDIX F: Relative risks of all cause, cardiopulmonary disease, lung cancer, and ischemic heart disease mortalities under 8 sensitivity scenarios

Table F1 Relative risks of all cause mortality (RR_{AC}) associated with $PM_{2\ 5\_Total}$ and $PM_{2\ 5\_No\ Dust}$ under 8 sensitivity scenarios for 132 countries with $PM_{2\ 5}$ and mortality data, by subregion (95% confidence intervals)

WHO Subregion	**RR_{AC} associated with $PM_{2\ 5}$**							
	Selection of C-R function		**Theoretical minimum**				**Maximum exposure threshold**	
	Scenario 2 Total Log-linear, Ref 5 8	Scenario 2 No Dust Log-linear, Ref 5 8	Scenario 3_Total Linear, Ref 2 1	Scenario 3_No Dust Linear, Ref 0 8	Scenario 4 Total Log-linear, Ref 2 1	Scenario 4 No Dust Log-linear, Ref 0 8	Scenario 5 Linear, Ref 5 8, Max 30	Scenario 6 Linear, Ref 5 8, Max Hybrid
AFR-D	1 02 (1 01-1 03)	1 00 (1 00-1 00)	1 04 (1 02-1 05)	1 00 (1 00-1 01)	1 12 (1 07-1 17)	1 03 (1 02-1 04)	1 02 (1 01-1 04)	1 02 (1 01-1 04)
AFR-E	1 01 (1 00-1 01)	1 00 (1 00-1 00)	1 03 (1 02-1 05)	1 03 (1 02-1 05)	1 11 (1 06-1 15)	1 16 (1 10-1 23)	1 01 (1 00-1 01)	1 01 (1 00-1 01)
AMR-A	1 07 (1 04-1 10)	1 06 (1 04-1 08)	1 07 (1 04-1 10)	1 07 (1 04-1 11)	1 18 (1 11-1 26)	1 24 (1 14-1 36)	1 04 (1 02-1 06)	1 04 (1 02-1 06)
AMR-B	1 03 (1 02-1 04)	1 00 (1 00-1 01)	1 04 (1 02-1 06)	1 04 (1 02-1 06)	1 13 (1 08-1 19)	1 18 (1 11-1 26)	1 02 (1 01-1 03)	1 02 (1 01-1 03)
AMR-D	1 05 (1 03-1 08)	1 04 (1 02-1 05)	1 06 (1 03-1 08)	1 06 (1 03-1 08)	1 16 (1 09-1 23)	1 22 (1 13-1 32)	1 03 (1 02-1 04)	1 03 (1 02-1 04)
EMR-B	1 17 (1 10-1 25)	1 00 (1 00-1 00)	1 18 (1 10-1 28)	1 03 (1 02-1 04)	1 29 (1 17-1 42)	1 15 (1 09-1 21)	1 15 (1 08-1 22)	1 15 (1 08-1 23)
EMR-D	1 23 (1 14-1 34)	1 07 (1 05-1 11)	1 31 (1 16-1 48)	1 08 (1 05-1 12)	1 36 (1 21-1 53)	1 26 (1 15-1 38)	1 20 (1 11-1 30)	1 28 (1 15-1 42)
EUR-A	1 11 (1 07-1 16)	1 08 (1 05-1 11)	1 11 (1 06-1 16)	1 08 (1 05-1 12)	1 22 (1 13-1 32)	1 26 (1 15-1 38)	1 08 (1 04-1 11)	1 08 (1 04-1 11)
EUR-B	1 12 (1 07-1 17)	1 04 (1 03-1 06)	1 11 (1 06-1 17)	1 06 (1 03-1 09)	1 23 (1 14-1 34)	1 23 (1 13-1 33)	1 08 (1 05-1 12)	1 08 (1 05-1 12)
EUR-C	1 06 (1 04-1 09)	1 02 (1 01-1 02)	1 06 (1 04-1 09)	1 06 (1 03-1 08)	1 17 (1 10-1 24)	1 19 (1 11-1 28)	1 03 (1 02-1 05)	1 03 (1 02-1 05)
SEAR-B	1 11 (1 07-1 16)	1 09 (1 05-1 13)	1 10 (1 06-1 15)	1 09 (1 05-1 14)	1 22 (1 13-1 32)	1 28 (1 16-1 41)	1 07 (1 04-1 11)	1 07 (1 04-1 11)
SEAR-D	1 01 (1 01-1 02)	1 00 (1 00-1 00)	1 03 (1 02-1 05)	1 02 (1 01-1 03)	1 11 (1 07-1 16)	1 11 (1 06-1 15)	1 01 (1 00-1 01)	1 01 (1 00-1 01)

WPR-A	1.11 (1.06-1.15)	1.07 (1.05-1.11)	1.10 (1.05-1.15)	1.08 (1.05-1.12)	1.22 (1.13-1.31)	1.26 (1.15-1.38)	1.07 (1.04-1.11)	1.07 (1.04-1.11)
WPR-B	1.27 (1.16-1.39)	1.24 (1.14-1.36)	1.40 (1.21-1.64)	1.35 (1.18-1.55)	1.39 (1.23-1.58)	1.46 (1.26-1.70)	1.18 (1.10-1.28)	1.32 (1.17-1.49)

Table F2 Relative risks of cardiopulmonary disease mortality (RR_{CPD}) associated with $PM_{2\ 5\_Total}$ and $PM_{2\ 5\ No\ Dust}$ under 8 sensitivity scenarios for 132 countries with $PM_{2\ 5}$ and mortality data, by subregion

WHO Subregion	RR_{CPD} associated with $PM_{2.5}$							
	Selection of C-R function		Theoretical minimum				Maximum exposure threshold	
	Scenario 2 Total Log-linear, Ref 5 8	Scenario 2 No Dust Log-linear, Ref 5 8	Scenario 3_Total Linear, Ref 2 1	Scenario 3_No Dust Linear, Ref 0 8	Scenario 4_Total Log-linear, Ref 2 1	Scenario 4 No Dust Log-linear, Ref 0 8	Scenario 5 Linear, Ref 5 8, Max 30	Scenario 6 Linear, Ref 5 8, Max Hybrid
AFR-D	1 03 (1 02-1 04)	1 00 (1 00-1 00)	1 06 (1 04-1 08)	1 01 (1 00-1 01)	1 19 (1 12-1 27)	1 05 (1 03-1 06)	1 04 (1 02-1 06)	1 04 (1 02-1 06)
AFR-E	1 01 (1 01-1 01)	1 00 (1 00-1 00)	1 05 (1 03-1 07)	1 06 (1 03-1 08)	1 17 (1 11-1 24)	1 27 (1 17-1 38)	1 01 (1 01-1 01)	1 01 (1 01-1 01)
AMR-A	1 12 (1 08-1 16)	1 10 (1 06-1 13)	1 12 (1 07-1 17)	1 12 (1 07-1 17)	1 30 (1 18-1 42)	1 41 (1 25-1 59)	1 07 (1 04-1 10)	1 07 (1 04-1 10)
AMR-B	1 05 (1 03-1 06)	1 01 (1 00-1 01)	1 07 (1 04-1 10)	1 06 (1 04-1 09)	1 22 (1 14-1 30)	1 29 (1 18-1 41)	1 03 (1 02-1 04)	1 03 (1 02-1 04)
AMR-D	1 09 (1 06-1 12)	1 06 (1 04-1 08)	1 09 (1 06-1 13)	1 09 (1 06-1 13)	1 26 (1 16-1 36)	1 36 (1 22-1 51)	1 05 (1 03-1 06)	1 05 (1 03-1 06)
EMR-B	1 28 (1 18-1 40)	1 00 (1 00-1 00)	1 31 (1 18-1 45)	1 05 (1 03-1 07)	1 49 (1 30-1 71)	1 24 (1 15-1 34)	1 25 (1 15-1 36)	1 25 (1 15-1 37)
EMR-D	1 39 (1 24-1 56)	1 12 (1 08-1 16)	1 54 (1 31-1 83)	1 14 (1 08-1 19)	1 61 (1 37-1 90)	1 44 (1 27-1 63)	1 34 (1 20-1 50)	1 48 (1 27-1 72)
EUR-A	1 18 (1 12-1 25)	1 12 (1 08-1 17)	1 17 (1 10-1 25)	1 14 (1 08-1 20)	1 37 (1 23-1 53)	1 44 (1 27-1 64)	1 12 (1 07-1 18)	1 12 (1 07-1 18)
EUR-B	1 19 (1 12-1 27)	1 07 (1 05-1 10)	1 19 (1 11-1 27)	1 10 (1 06-1 14)	1 38 (1 24-1 55)	1 38 (1 23-1 54)	1 14 (1 08-1 19)	1 14 (1 08-1 19)
EUR-C	1 10 (1 06-1 14)	1 02 (1 02-1 03)	1 10 (1 06-1 15)	1 09 (1 06-1 13)	1 28 (1 17-1 39)	1 32 (1 20-1 45)	1 06 (1 03-1 08)	1 06 (1 03-1 08)
SEAR-B	1 18 (1 11-1 24)	1 14 (1 09-1 20)	1 17 (1 10-1 24)	1 16 (1 09-1 22)	1 36 (1 23-1 52)	1 47 (1 29-1 68)	1 12 (1 07-1 17)	1 12 (1 07-1 17)
SEAR-D	1 02 (1 01-1 03)	1 00 (1 00-1 00)	1 06 (1 03-1 08)	1 03 (1 02-1 04)	1 18 (1 12-1 26)	1 17 (1 11-1 24)	1 01 (1 01-1 01)	1 01 (1 01-1 01)
WPR-A	1 17 (1 11-1 24)	1 12 (1 08-1 16)	1 17 (1 10-1 24)	1 14 (1 08-1 19)	1 36 (1 22-1 51)	1 44 (1 27-1 63)	1 12 (1 07-1 17)	1 12 (1 07-1 17)
WPR-B	1 45 (1 27-1 64)	1 41 (1 25-1 59)	1 72 (1 40-2 13)	1 62 (1 35-1 96)	1 68 (1 40-2 01)	1 81 (1 48-2 23)	1 31 (1 18-1 45)	1 52 (1 29-1 78)

Table F3 Relative risks of lung cancer mortality (RR_{LC}) associated with $PM_{2\ 5\_Total}$ and $PM_{2\ 5\_No\ Dust}$ under 8 sensitivity scenarios for 132 countries with $PM_{2\ 5}$ and mortality data, by subregion (95% confidence intervals)

WHO Subregion	**RR_{LC} associated with $PM_{2\ 5}$**							
	Selection of C-R function		**Theoretical minimum**				**Maximum exposure threshold**	
	Scenario 2 Total Log-linear, Ref 5 8	Scenario 2 No Dust Log-linear, Ref 5 8	Scenario 3_Total Linear, Ref 2 1	Scenario 3_No Dust Linear, Ref 0 8	Scenario 4_Total Log-linear, Ref 2 1	Scenario 4_No Dust Log-linear, Ref 0 8	Scenario 5 Linear, Ref 5 8, Max 30	Scenario 6 Linear, Ref 5 8, Max Hybrid
AFR-D	1 03 (1 02-1 05)	1 00 (1 00-1 00)	1 07 (1 03-1 11)	1 01 (1 00-1 01)	1 22 (1 11-1 35)	1 05 (1 03-1 08)	1 04 (1 02-1 07)	1 04 (1 02-1 07)
AFR-E	1 01 (1 01-1 02)	1 00 (1 00-1 00)	1 06 (1 02-1 09)	1 06 (1 03-1 10)	1 20 (1 10-1 31)	1 30 (1 15-1 49)	1 01 (1 00-1 01)	1 01 (1 00-1 01)
AMR-A	1 13 (1 07-1 20)	1 11 (1 05-1 17)	1 13 (1 05-1 21)	1 13 (1 05-1 21)	1 34 (1 16-1 54)	1 47 (1 22-1 77)	1 08 (1 03-1 12)	1 08 (1 03-1 12)
AMR-B	1 05 (1 03-1 08)	1 01 (1 00-1 01)	1 08 (1 03-1 13)	1 07 (1 03-1 12)	1 24 (1 12-1 39)	1 33 (1 16-1 54)	1 04 (1 01-1 06)	1 04 (1 01-1 06)
AMR-D	1 10 (1 05-1 15)	1 07 (1 03-1 10)	1 10 (1 04-1 17)	1 10 (1 04-1 17)	1 29 (1 14-1 47)	1 41 (1 19-1 67)	1 05 (1 02-1 08)	1 05 (1 02-1 08)
EMR-B	1 32 (1 15-1 52)	1 00 (1 00-1 00)	1 35 (1 13-1 60)	1 05 (1 02-1 09)	1 56 (1 26-1 94)	1 28 (1 13-1 44)	1 27 (1 11-1 47)	1 28 (1 11-1 48)
EMR-D	1 45 (1 21-1 74)	1 14 (1 07-1 21)	1 62 (1 22-2 14)	1 15 (1 06-1 25)	1 71 (1 32-2 23)	1 50 (1 23-1 84)	1 38 (1 14-1 66)	1 54 (1 20-1 98)
EUR-A	1 21 (1 10-1 32)	1 14 (1 07-1 21)	1 19 (1 08-1 33)	1 15 (1 06-1 25)	1 42 (1 20-1 69)	1 51 (1 23-1 84)	1 14 (1 06-1 23)	1 14 (1 06-1 23)
EUR-B	1 22 (1 11-1 34)	1 08 (1 04-1 12)	1 21 (1 08-1 35)	1 11 (1 05-1 18)	1 44 (1 20-1 72)	1 43 (1 20-1 70)	1 15 (1 06-1 25)	1 15 (1 06-1 25)
EUR-C	1 11 (1 06-1 17)	1 03 (1 01-1 04)	1 12 (1 05-1 19)	1 10 (1 04-1 16)	1 31 (1 15-1 50)	1 36 (1 17-1 58)	1 06 (1 03-1 10)	1 06 (1 03-1 10)
SEAR-B	1 20 (1 10-1 31)	1 16 (1 08-1 25)	1 19 (1 07-1 31)	1 17 (1 07-1 29)	1 42 (1 19-1 68)	1 54 (1 25-1 90)	1 13 (1 05-1 22)	1 13 (1 05-1 22)
SEAR-D	1 02 (1 01-1 04)	1 00 (1 00-1 00)	1 06 (1 03-1 10)	1 03 (1 01-1 05)	1 21 (1 10-1 33)	1 20 (1 10-1 31)	1 01 (1 00-1 02)	1 01 (1 00-1 02)
WPR-A	1 19 (1 10-1 30)	1 14 (1 07-1 21)	1 18 (1 07-1 31)	1 15 (1 06-1 25)	1 41 (1 19-1 67)	1 50 (1 23-1 84)	1 13 (1 05-1 22)	1 13 (1 05-1 22)
WPR-B	1 51 (1 24-1 86)	1 47 (1 22-1 78)	1 82 (1 28-2 59)	1 71 (1 25-2 33)	1 79 (1 35-2 38)	1 95 (1 41-2 70)	1 35 (1 13-1 60)	1 60 (1 22-2 11)

Table F4 Relative risks of ischemic heart disease (RR_{IHD}) associated with $PM_{2 5\_Total}$ and $PM_{2 5\_No Dust}$ under 8 sensitivity scenarios for 132 countries with $PM_{2 5}$ and mortality data, by subregion (95% confidence intervals)

WHO Subregion	RR_{IHD} associated with $PM_{2.5}$							
	Selection of C-R function		**Theoretical minimum**				**Maximum exposure threshold**	
	Scenario 2_{Total} Log-linear, Ref 5 8	Scenario $2_{\_No Dust}$ Log-linear, Ref 5 8	Scenario $3_{\_Total}$ Linear, Ref 2 1	Scenario $3_{\_No Dust}$ Linear, Ref 0 8	Scenario $4_{\_Total}$ Log-linear, Ref 2 1	Scenario $4_{\_No Dust}$ Log-linear, Ref 0 8	Scenario 5 Linear, Ref 5 8, Max 30	Scenario 6 Linear, Ref 5 8, Max Hybrid
AFR-D	1 06 (1 04-1 08)	1 00 (1 00-1 00)	1 13 (1 08-1 18)	1 01 (1 01-1 02)	1 45 (1 29-1 62)	1 10 (1 07-1 13)	1 08 (1 05-1 12)	1 08 (1 05-1 12)
AFR-E	1 02 (1 02-1 03)	1 00 (1 00-1 00)	1 11 (1 07-1 15)	1 12 (1 08-1 17)	1 39 (1 26-1 54)	1 64 (1 40-1 90)	1 02 (1 01-1 02)	1 02 (1 01-1 02)
AMR-A	1 26 (1 17-1 35)	1 21 (1 14-1 28)	1 26 (1 16-1 37)	1 26 (1 16-1 37)	1 72 (1 45-2 02)	2 04 (1 63-2 53)	1 15 (1 09-1 20)	1 15 (1 09-1 20)
AMR-B	1 10 (1 07-1 14)	1 01 (1 01-1 02)	1 15 (1 10-1 21)	1 14 (1 09-1 19)	1 50 (1 32-1 70)	1 71 (1 44-2 01)	1 07 (1 04-1 09)	1 07 (1 04-1 09)
AMR-D	1 19 (1 12-1 25)	1 13 (1 09-1 17)	1 21 (1 13-1 29)	1 21 (1 13-1 29)	1 62 (1 39-1 87)	1 90 (1 55-2 31)	1 10 (1 06-1 14)	1 10 (1 06-1 14)
EMR-B	1 68 (1 43-1 97)	1 00 (1 00-1 00)	1 76 (1 44-2 14)	1 10 (1 07-1 14)	2 29 (1 77-2 94)	1 58 (1 37-1 81)	1 59 (1 35-1 87)	1 60 (1 36-1 89)
EMR-D	1 99 (1 60-2 45)	1 27 (1 18-1 36)	2 49 (1 80-3 43)	1 31 (1 19-1 44)	2 72 (1 98-3 67)	2 14 (1 68-2 69)	1 84 (1 48-2 28)	2 27 (1 70-3 02)
EUR-A	1 42 (1 27-1 57)	1 27 (1 18-1 37)	1 40 (1 24-1 58)	1 31 (1 19-1 44)	1 93 (1 57-2 35)	2 15 (1 69-2 70)	1 28 (1 17-1 39)	1 28 (1 17-1 39)
EUR-B	1 45 (1 29-1 62)	1 15 (1 10-1 20)	1 43 (1 26-1 63)	1 22 (1 14-1 31)	1 97 (1 59-2 42)	1 95 (1 58-2 38)	1 31 (1 19-1 43)	1 31 (1 19-1 43)
EUR-C	1 22 (1 15-1 30)	1 05 (1 04-1 07)	1 23 (1 14-1 32)	1 20 (1 13-1 28)	1 66 (1 42-1 94)	1 78 (1 48-2 11)	1 12 (1 08-1 17)	1 12 (1 08-1 17)
SEAR-B	1 40 (1 26-1 55)	1 32 (1 21-1 44)	1 39 (1 24-1 56)	1 36 (1 22-1 51)	1 91 (1 56-2 32)	2 23 (1 73-2 85)	1 26 (1 16-1 37)	1 26 (1 16-1 37)
SEAR-D	1 04 (1 03-1 06)	1 00 (1 00-1 00)	1 12 (1 08-1 17)	1 06 (1 04-1 09)	1 42 (1 27-1 58)	1 40 (1 26-1 54)	1 02 (1 01-1 03)	1 02 (1 01-1 03)
WPR-A	1 39 (1 26-1 54)	1 27 (1 18-1 36)	1 38 (1 23-1 54)	1 31 (1 19-1 44)	1 90 (1 55-2 30)	2 14 (1 68-2 69)	1 26 (1 16-1 37)	1 26 (1 16-1 37)
WPR-B	2 16 (1 70-2 73)	2 05 (1 64-2 54)	3 13 (2 09-4 68)	2 76 (1 93-3 95)	2 95 (2 10-4 08)	3 46 (2 34-5 03)	1 76 (1 44-2 15)	2 41 (1 76-3 28)