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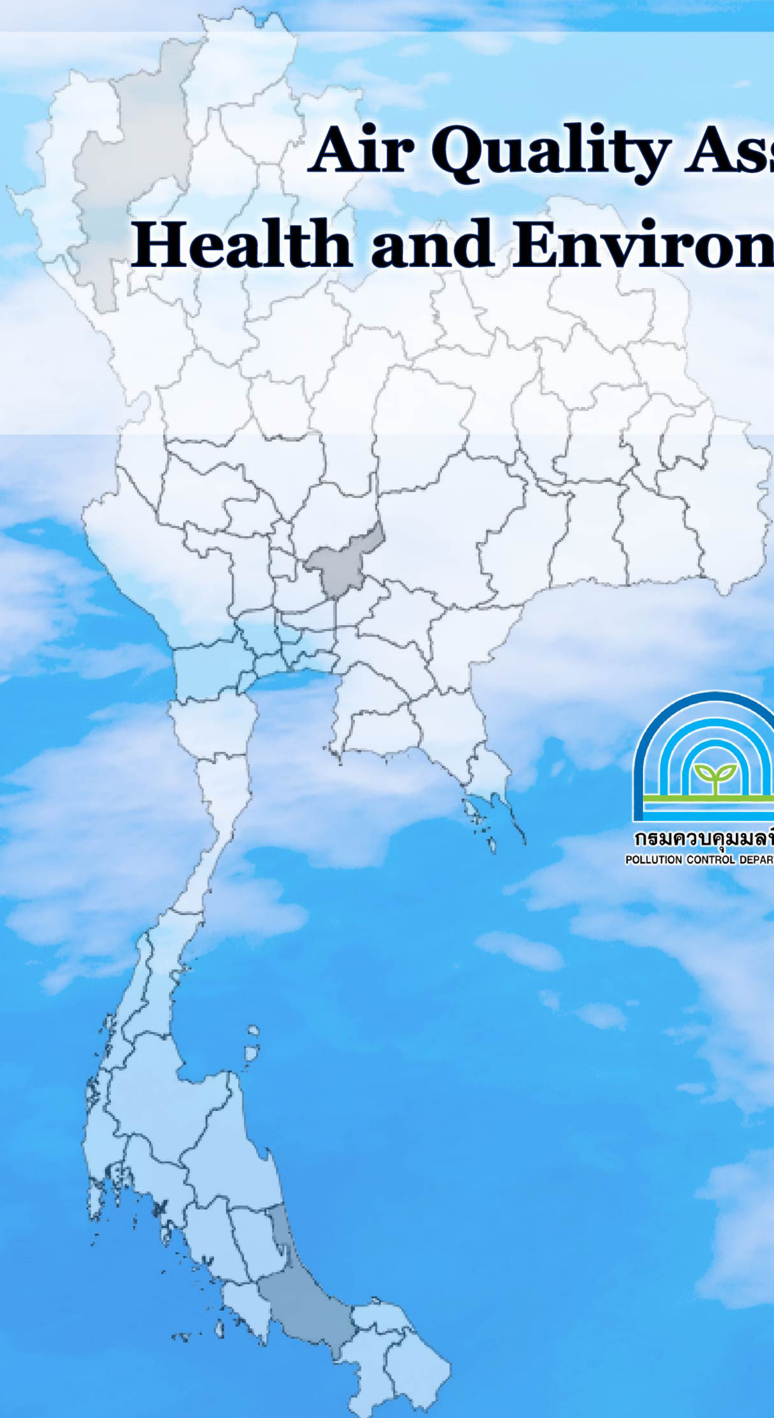
Air Quality Assessments for Health and Environment Policies in Thailand



by

กรมควบคุมมลพิษ
POLLUTION CONTROL DEPARTMENT

Chulabhorn Research Institute

กรมอนามัย
DEPARTMENT OF HEALTH

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Preface

The information contained within this document is taken from a report submitted to the UN Environment in 2018 in fulfillment of the aims of a project entitled, **“The Air Quality Assessments for Health and Environment Policies in Thailand”**. This project had the main aim of enhancing the capacity of targeted countries in Asia, including Thailand, to strengthen and use data and information to assess ambient air quality and support the development and implementation of evidence-based policies on ambient air quality and health. The project was supported by the UN Environment and involved the Thai Pollution Control Department under the Ministry of Natural Resources and Environment and the Thai Department of Health under the Ministry of Public Health, as well as the Center of Excellence on Environmental Health and Toxicology (EHT), with the Chulabhorn Research Institute (CRI) as the coordinating institution. The collaborating partners on this project agree to make this information available to the public as reference for further efforts in the assessment of air quality and health impacts in Thailand, as well as other countries for which this information may be beneficial.

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Executive Summary

I. Project Overview and Stakeholders

1. The Air Quality Assessments for Health and Environment Policies in Thailand is a project of the UN Environment aimed at enhancing capacity of targeted countries in Asia (Mongolia, Sri Lanka, Thailand) to strengthen and use data and information to assess ambient air quality and support the development and implementation of evidence-based policies on ambient air quality and health.
2. This project is supported by the Pollution Control Department under the Ministry of Natural Resources and Environment and the Department of Health under the Ministry of Public Health, and is implemented by the Centre of Excellence on Environmental Health and Toxicology (EHT), with the Chulabhorn Research Institute (CRI) as the coordinating institution, in consultation with the UN Environment.
3. Air Quality Management (AQM) in Thailand involves several governmental agencies, with the key one being the Pollution Control Department (PCD), under the Ministry of Natural Resources and Environment (MoNRE).
4. Health information is collected by the Ministry of Public Health, but the system for data collection is complex, and not all health data is automatically available. For example, in Bangkok, health data is collected at the level of the hospital, and the collection system is dependent on the individual hospital.
5. Thailand has air quality standards for CO, NO_2, SO_2, TSP, PM_{10}, $PM_{2.5}$, O_3, Pb, and many volatile organic compounds (VOCs), including benzene and 1,3-butadiene.
6. Thailand uses an Air Quality Index (AQI) system to report air pollution data to the public and uses 6 air pollutants for calculation: $PM_{2.5}$ and PM_{10}, ozone, carbon monoxide, nitrogen dioxide and sulfur dioxide.
7. Other stakeholders involved with Air Quality Management include the Ministry of Energy (MOE), Ministry of Industry (MOI), Office of the Prime Minister, non-profit organizations, and research and academic institutions. All stakeholders were invited to participate in the Conference on Air Quality Assessment for Health and Environmental Policies in Thailand, held at the Miracle Grand Convention Hotel, Bangkok, on November 6th, 2017.
8. In this study, the 3 air pollutants of interest are $PM_{2.5}$, PM_{10}, and ozone. $PM_{2.5}$ and PM_{10} are key air pollutants of concern globally, with a wealth of literature on health impacts from exposure, while ozone is an air pollutant with continually elevated levels in Thailand.

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II. Introduction to Air Pollution and Health Effects

9. Health effects of air pollutants is dependent on exposure. The amount of internal exposure, i.e. the amount of chemical pollutant(s) that gets into the body and therefore is able to elicit a response, is not the same as the concentration measured in ambient air, external to the exposed individual.

10. Short-term exposure to particulate matter has been associated with cardiovascular and respiratory mortality and long-term exposure to fine particulate matter has been linked to increased morality risk.

11. There is no evidence for a threshold, below which no effects of $PM_{2.5}$ on mortality are expected to occur, and the same has been shown for PM_{10} and cardiovascular mortality.

12. Studies have established mechanistic bases for the health effects associated with many of these pollutants, e.g. $PM_{2.5}$ is associated with systemic inflammation, oxidative stress and electrical processes of the heart, PM exposure is linked to atherosclerosis, cancer is a concern with exposures to carcinogenic air pollutants, including compounds such as benzene and 1,3-butadiene, and air pollutant exposures have been linked to various other diseases, including diabetes and neurological effects.

13. One of the difficulties in air pollution research, particularly in human studies, is the disconnect between exposure and disease observation. Several important factors, including ambient temperature, volatility of the air pollutant(s), wind velocity and direction, inhalation rate, lipophilicity of the air pollutant(s), and rate of metabolism of the air pollutant(s), play key roles in the concentration of the pollutant(s) that reaches their target tissues.

14. The use of key indicators of internal exposure, e.g. blood levels of pollutants, as well as indicators of early biological changes that are associated with disease manifestation, e.g. DNA damage, are required to be able to provide that important link between ambient exposure and ultimate manifestation of disease.

15. There are some limitations to the use of biomarkers, including sensitivity, specificity and cost, and the analysis and interpretation of biomarker levels requires expertise; however, as the science of the health impacts of air pollution progresses, it is important for these markers to increasingly be used to help provide a strong link between patterns of exposure to air pollutants and the observed incidence of disease and mortality.

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III. Thailand Situational Assessment: Air Quality Standards, National Action Plans and Related Legislation

16. Setting air quality standards in Thailand is done according to the Enhancement and Conservation of National Environmental Quality Act (1992, amended 2018), which specifies that this must involve scientific principles and evidence as the important bases, and must consider the economic, social and technological aspects involved.

17. The Act gives the National Environmental Board the authority to revise environmental quality standards concomitant with scientific and technological advances, as well as economic and social changes.

18. The Pollution Control Department (PCD), under the Ministry of Natural Resources and Environment (MoNRE), is responsible for drafting environmental quality standards and making recommendations to the national environmental board for consideration and approval.

19. The PCD drafts environmental quality standards by monitoring, collecting and verifying air quality data, according to methods specified by regulations, to be used as baseline/background information for the country towards setting appropriate standards; considering impacts on the environment and human health in setting appropriate standards; and reviewing the latest information available from international organizations in terms of various air quality guidelines, and other developed countries in terms of their national air quality standards. Input from various governmental agencies and other stakeholders is also taken into account.

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IV. Thailand Situational Assessment: Air Monitoring Stations and Health Surveillance

20. As of 2018, a total of total of 63 monitoring stations have been established around the country: 28 in central Thailand, which contains the capital – Bangkok; 15 in the North, which suffers from haze from open burning; 11 in the East, which is the important industrial zone; 6 in the South, which is affected by transboundary haze; and 3 in the North-East, which is an important agricultural area).

21. The monitoring stations conduct two types of monitoring: automated continuous monitoring, e.g. for $PM_{2.5}$, PM_{10}, and manual non-continuous monitoring, e.g. for benzene and other volatile organic compounds (VOCs).

22. Healthcare is administered at the regional, provincial, district and sub-district levels. Health data for individuals is collected and checked at the sub-district levels before being sent to the district level where the data is cleansed and verified. The data is then sent to the provincial level to be processed and analyzed, before being aggregated at the regional level and the aggregated data is quality-checked and analyzed at the national level.

23. Health status is categorized according to the International Statistical Classification of Diseases and Related Health Problems, 10th revision (ICD10).

V. Study Design and Methodology

24. Air quality monitoring data was from stations in 5 representative provinces from five geographical regions in Thailand: Chiang Mai (north), Kon Kaen (northeast), Rayong (east), Saraburi (central) and Songkhla (south). These stations were selected as they monitor all the pollutants of interest for this study.

25. Health effects data was provided by hospitals under the jurisdiction of the Ministry of Public Health (MoPH). The health effects of concern selected for analysis in this study are cancer (ICD-10 classification C), diseases of the eye (ICD-10 classification H), cardiovascular diseases (ICD-10 classification I) and respiratory diseases (ICD-10 classification J).

26. Raw health data provided by the Ministry of Public Health were in the form of anonymized individual out-patient department (OPD) records divided into 13 age groups: 0-4, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, and 60+ years, for each ICD-10 health effects code of interest: H10-H11, H15-H22, H40-H42, I10-I16, I20-I25, I26-I28, I30-I52, I60-I69, I70-I79, I80-I89, I95-I99, J00-J06, J09-J18, J20-J22, J30-J39, J40-J47, J60-J70, J80-J86, J90-J94, J95, and J96-J99.

27. The three provinces were selected for potentially different exposure scenarios and levels. Chiang Mai is known to be affected by air pollutants from open burning and geological features (mountains) that affect air flow and trap pollutants. Saraburi is known to have stone mining and processing activities that can be important sources of pollutants. Songkhla was chosen for being a hypothetically less-polluted area.

VI. Analysis of Associations Between Air Quality and Health Effects Data

28. Analysis was done for weekly pollutant levels and weekly OPD patient numbers. The weekly pollution levels were calculated as follows: first, median values were calculated for each day (24-hour period) and then for each week (7-day period). The final values expressed are weekly median pollutant values from the air monitoring stations.

29. The weekly OPD patient numbers are the sum of OPD patient numbers across the same 7-day period as the collected pollutant data.

30. The generalized linear model (GLM) was used for data analysis with the Poisson link function. The model is a simple regression model with single pollutants as predictors and the number of OPD admissions as the response variable. The model did not correct for seasonal trends and did not include any interaction terms or potential confounding factors, such as humidity and wind speed, except for weekend trends (i.e. five-day and two-day intervals).

31. To measure the impact that diseases have on the lives of people, the World Health Organization (WHO) uses a metric called the Disability-Adjusted Life Year (DALY) to quantify the burden of disease. The DALY is the sum of two components: DALY = YLL + YLD, where YLL is "years of life lost", which is a measure of the mortality of the diseases, and YLD is "years lost due to disability", which measures the burden of living with diseases or disabilities.

32. A health impact function was used to assess the effect of each pollutant on the excess number of patients by disease categories of interest: $\Delta E_{morbid} = \left[1 - e^{-\beta(C_a - C_0)}\right] \times I_r \times E_{pop}$, where ΔE_{morbid} is the estimated excess number of patients incurred by exposure to an excess amount of pollutant of interest; E_{pop} is the estimated population of the district of interest; β is the exposure-response coefficient (ERC); C_a is the annual average concentration of the pollutant; C_0 is the WHO air quality guideline value for the pollutant; and I_r is the baseline incidence rate of a health outcome category of interest.

33. The Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE) software package was used to calculate health economic impacts from air pollution based on air monitoring data and statistical models.

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VII. Results

34. Most of the acute upper respiratory infection patients went to receive treatment at the respective hospitals on Mondays (17.6%), with the least number of patients going to receive treatment on Sundays (9.3%).

35. The majority of patients were in the 0-4 years age group (26.8%), followed by the 5-9 years age group (13.5%) and the 60+ years age group (7.9%).

36. According to the Thai AQI standard for $PM_{2.5}$, patients were mostly in the "Excellent" air quality classification. Saraburi seemed to be the most affected, where patients were distributed most equally among each $PM_{2.5}$ classification. Khon Kaen also had a lot of patients in the "Unhealthy" $PM_{2.5}$ classification.

37. Saraburi had the greatest number of patients in the poorer air quality classifications as it pertains to PM_{10}.

38. There was a total of 64 significant observations (RR>1.0) in the Chiang Mai data when ICD-10 data were grouped according to disease classification. The greatest number of significant observations were in the 50-54 years (15.63%) age group. The greatest number of significant observations were seen for respiratory effects (43.75%). When looking at the relative risk values, the relationships between cancer and ozone in the 5-9 years age group (4.72) and 30-34 age group (2.13) stand out as being quite large and may require a closer assessment.

39. When separated out into sub-disease classifications, a total of 112 significant observations (RR>1.0) were seen in the Chiang Mai data. The greatest number of significant observations were seen for the J00-J06 classification - acute upper respiratory infections (25.00%). When considering the relative risk values, the relationships between cancer (C81-C96) and ozone in the 5-9 age group (8.86), eye diseases (H15-H22) and ozone in the 30-34 age group (2.29), cardiovascular disease (I95-I99) and ozone (29.61) in the 30-34 age group, respiratory disease (J80-J86) and ozone in the 30-34 age group (13.84), cancer (C30-C39) and ozone in the 55-59 age group (2.32), and cardiovascular disease (I70-I79) and ozone in the 55-59 age group (4.58) stand out as being quite large and may require a closer assessment.

40. There was a total of 42 significant observations (RR>1.0) in the Saraburi data when ICD-10 data were grouped according to disease classification. The greatest number of significant observations were in the 55-59 years and 60+ years age groups (each 16.67%). The greatest number of significant observations were seen for respiratory effects (40.48%).

Executive Summary

VII. Results (continued)

41. When separated out into sub-disease classifications, a total of 103 significant observations (RR>1.0) were seen in the Saraburi data. The greatest number of significant observations were seen in the 60+ years age group (15.53%). The greatest number of significant observations were seen for the J00-J06 classification - acute upper respiratory infections (16.51%).

42. There was a total of 73 significant observations (RR>1.0) in the Songkhla data when ICD-10 data were grouped according to disease classification. The greatest number of significant observations were in the 50-54 years and 60+ years groups (both 10.96%). The greatest number of significant observations were seen for cardiovascular effects (38.36%).

43. When separated out into sub-disease classifications, a total of 181 significant observations (RR>1.0) were seen in the Songkhla data. The greatest number of significant observations were seen in the 50-54 years and 60+ years age group (each 11.60%). The greatest number of significant observations were seen for the H10-H11 – disorders of conjunctiva, and J30-J39 classification - other diseases of the upper respiratory tract (each 9.95%).

44. Overall, for all three provinces, there were 192 significant observations (RR>1.0) associated with ozone, with the disease classification with highest significant observations in association with ozone levels being J00-J06 - acute upper respiratory infections.

45. Overall, for all three provinces, the disease classification with highest significant observations in association with $PM_{2.5}$ levels were J00-J06 - acute upper respiratory infections.

46. Overall, for all three provinces, the disease classification with highest significant observations in association with PM_{10} levels were J00-J06 - acute upper respiratory infections.

47. The greatest number of DALYs, i.e. the greatest negative impacts on health, were seen in Songkhla (150.6-264.2 years per 1,000 population or 15,056-26,415 years per 100,000 population. Saraburi was next with 78.0-317.1 years per 1,000 population or 7,800-31,706 year per 100,000 population, while Chiang Mai had a range of DALYs from 32.8-176.1 years per 1,000 population or 3,283-17,612 years per 100,000 population. While Songkhla had the highest lower bound value of the DALYs at 150.6 years, the highest upper bound value was for Saraburi at 317.1 years.

Executive Summary

VII. Results (continued)

48. If the air concentrations of PM_{10} and $PM_{2.5}$ in Chiang Mai could be reduced the WHO Interim Target 1, the economic valuation of the total health benefits for that province would amount to 1.86 billion Thai Baht in 2017. Reduction of air concentrations of the two pollutants to WHO Interim Target 2 would have a total health benefit amounting to 2.09 billion Thai baht, and reduction to WHO Interim Target 3 would have a total health benefit amounting to 2.13 billion Thai baht for that province. If the air concentrations of the two pollutants were below the WHO guidelines, the total economic health benefits for Chiang Mai are estimated at 2.18 billion Thai baht.

49. If the air concentrations of PM_{10} and $PM_{2.5}$ in Saraburi could be reduced to WHO Interim Target 1, the economic valuation of the total health benefits for that province would amount to 2.54 billion Thai Baht in 2017. Reduction of air concentrations of the two pollutants to WHO Interim Target 2 would have a total health benefit amounting to 2.63 billion Thai baht, and a reduction to WHO Interim Target 3 would have a total health benefit amounting to 2.70 billion Thai baht for that province. If the air concentrations of the two pollutants were below the WHO guidelines, the total economic health benefits for Saraburi are estimated at 2.73 billion Thai baht.

50. If the air concentrations of PM_{10} and $PM_{2.5}$ in Songkhla could be reduced to WHO Interim Target 1, the economic valuation of the total health benefits for that province would amount to 1.48 billion Thai Baht in 2017. Reduction of air concentrations of the two pollutants to WHO Interim Target 2 would have a total health benefit amounting to 1.12 billion Thai baht, and a reduction to WHO Interim Target 3 would have a total health benefit amounting to 1.30 billion Thai baht for that province. If the air concentrations of the two pollutants were below the WHO guidelines, the total economic health benefits for Songkhla are estimated at 1.30 billion Thai baht.

VIII. Conclusions

51. In this report, relative risks associated with increased exposures to 3 selected air pollutants – $PM_{2.5}$, PM_{10} and ozone – were calculated based on air quality and health monitoring data in 3 provinces in Thailand over a period of 5 years (2012-2016). Disability-adjusted life years were also calculated for each of the provinces as a sum total of the DALYs for each of the ICD-10 disease classifications. Subsequently, the predicted size of the populations in the 3 provinces affected by the levels of exposure to the 3 aforementioned air pollutants at levels greater than the national standards were estimated. Finally, an estimate of the economic benefits from various levels of environmental management (reduction in exposure concentrations to the WHO Interim Targets 1, 2 or 3, or to below the WHO Guideline values) was calculated for all three provinces.

52. Economic benefits were estimated to total 1.86 billion (Interim Target 1), 2.10 billion (Interim Target 2), 2.13 billion (Interim Target 3), and 2.18 billion (reduction to below WHO Guideline values) Thai Baht for Chiang Mai province; 2.54 billion (Interim Target 1), 2.63 billion (Interim Target 2), 2.70 billion (Interim Target 3) and 2.73 billion (reduction to below WHO Guideline values) Thai Baht for Saraburi province; and 1.48 billion (Interim Target 1), 1.12 billion (Interim Target 2), 1.30 billion (Interim Target 3) and 1.30 billion (reduction to below WHO Guideline values) Thai Baht for Songkhla province for reduction of $PM_{2.5}$ and PM_{10} levels. With the potential economic benefits estimated, what is needed is a cost analysis to determine at which remediated exposure levels the benefits would significantly outweigh the management/implementation costs.

53. There are certain inefficiencies and factors leading to elevated health risks associated with air pollution in Thailand that need to be addressed.

54. It is clear that the sources of air pollutants present in the country is quite varied across different locations, which means that there is no single policy recommendation that can be made to cover all situations. Awareness of the local situation, and policies specific for those sources and situations are required.

55. Health data collected at the Ministry of Public Health is not complete. This is because there are hospitals and health care services, e.g. clinics, that are not within the data collection system of the Ministry of Public Health. Many of these hospitals collect their own data, but much of this is not submitted to the Ministry of Public Health, and the data collection systems are not equivalent or compatible, e.g. different types of data collected and different codes used, etc. Classification of cases of morbidity and, in particular, mortality may also not be accurate in terms of the actual primary cause, which means that important links are potentially lost.

56. The data would tend to indicate not only variability in risk due to local emission sources, but also variability in risk to certain sensitive sub-populations, e.g. people 60+ years of age, which means that these sensitive sub-populations may need to be under special consideration for any policy measures.

IX. Policy Recommendations

57. Control and minimization of air pollutant emissions at the source, through increasing awareness and making the data/information available, and accessible, to the public, as well as to all business owners and regulatory authorities involved.
58. Increase effectiveness of control measures through reviewing/revising (as needed) national air quality standards and emissions standards, as well as building the capacity of local governing bodies for management and control of air pollutant emissions.
59. Develop a system for health data collection, for correct/accurate/appropriate disease diagnosis and categorization for cases of morbidity and mortality, and initiate/improve collaborations with private hospitals, and those under the jurisdiction of the Ministry of the Interior or universities, such that morbidity and mortality data are reported to the Ministry of Public Health.
60. Integrate health and environmental monitoring data in a national database.
61. Disseminate information on health impacts of air pollutant exposures, with focus on appropriate health protection.
62. Historical data (both hourly air pollution data and anonymized health data) should be open to the public to encourage other researchers and the general public to make full use of the data.
63. Prepare a national report on the current situation of health impacts of air pollution every two years, with one of the main aims being to clearly illustrate the linkage between health and the environment.
64. Organize regular academic platforms for the discussion of the most up-to-date situation of air pollution and health impacts in the country, as well as the latest research results in this area.
65. Promote research on health impacts of air pollution, with special focus on the situation in the country. Key areas for which there is currently limited information include, for example, the use of biomarkers for monitoring exposure and effects and the socioeconomic impacts of air pollution.

Project Committee

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Air Quality Assessments for Health and Environment Policies in Thailand

PROJECT OVERVIEW AND STAKEHOLDER MAPPING

The Air Quality Assessments for Health and Environment Policies in Thailand is a project of the UN Environment aimed at enhancing capacity of targeted countries in Asia (Mongolia, Sri Lanka, Thailand) to strengthen and use data and information to assess ambient air quality and support the development and implementation of evidence-based policies on ambient air quality and health. The project addresses the gaps in the knowledge base on ambient air quality and health impacts and attempts to connect the two areas in support of coherent policy-making. This project is supported by the Pollution Control Department under the Ministry of Natural Resources and Environment and the Department of Health under the Ministry of Public Health, and is implemented by the Centre of Excellence on Environmental Health and Toxicology (EHT), with the Chulabhorn Research Institute (CRI) as the coordinating institution, in consultation with the UN Environment.

Air Quality Management (AQM) in Thailand involves several governmental agencies, with the key one being the Pollution Control Department, under the Ministry of Natural Resources and Environment. The process for setting air quality standards (AQS) in Thailand is described in Section IV: Thailand Situational Assessment - Air Quality Standards, National Action Plans and Related Legislation. Health information is collected by the Ministry of Public Health, but the system for data collection is complex, and not all health data is automatically available. For example, in Bangkok, health data is collected at the level of the hospital, and the collection system, e.g. software database, is dependent on the individual hospital. Health data from other provinces is collected provincially and eventually is kept in a centralized database at the Ministry of Public Health.

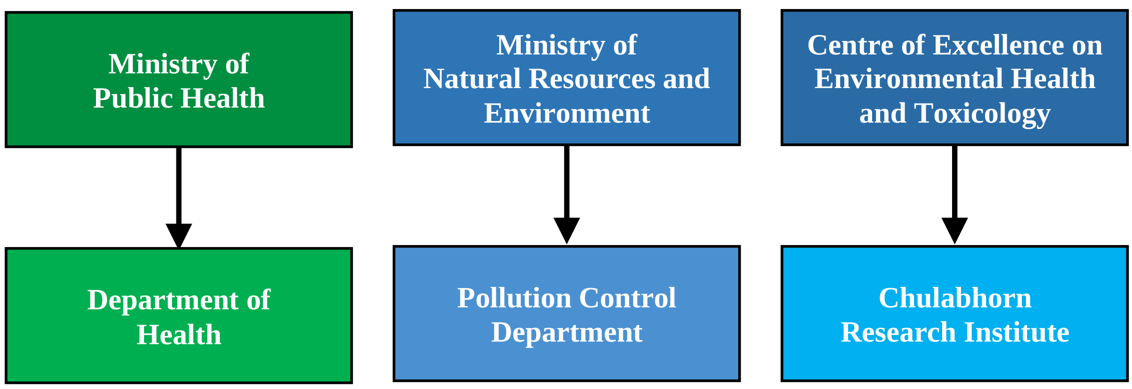

Figure 1. Key Project Stakeholders.

In terms of the current situation for air quality management in the country, Thailand has air quality standards for the following pollutants:

Table 1. Thailand Ambient Air Quality Standards (Average).

Air Pollutants	1-hr	8-hr	24-hr	1-month	1-year
Carbon Monoxide (CO) (ppm)	30	9	-	-	-
Nitrogen Dioxide (NO_2) (ppm)	0.17	-	-	-	0.03
Sulfur Dioxide (SO_2) (ppm)	0.3	-	0.12	-	0.04
Total Suspended Particulates (TSP) (mg/m^3)	-	-	0.33	-	0.1
Particulate Matter < 10 microns (PM_{10}) (mg/m^3)	-	-	0.12	-	0.05
Particulate Matter < 2.5 microns ($PM_{2.5}$) (mg/m^3)	-	-	0.05	-	0.025
Ozone (O_3) (ppm)	1.0	0.07	-	-	-
Lead (Pb) (mg/m^3)	-	-	-	1.5	-

Source: http://www.pcd.go.th/info_serv/reg_std_airsnd01.html

Table 2. Thailand Air Quality Standards.

Volatile Organic Compounds (VOCs)	Annual Average Standard ($\mu g/m^3$)	Guideline value 24 hr. average ($\mu g/m^3$)
Acetaldehyde		860
Acrylonitrile		10
Benzene	1.7	7.6
Benzyl Chloride		12
1,3-Butadiene	0.33	5.3
Bromomethane		190
Carbon Tetrachloride		150
Chloroform	0.43	57
1,2-Dibromoethane		370
1,4-Dichlorobenzene		1100
1,2-Dichloroethane	0.4	48
Dichloromethane	22	210
1,2-Dichloropropane	4	82
1,4-Dioxane		860
2-Propenal/acrolein		0.55
Tetrachloroethylene	200	400
1,1,2,2-Tetrachloroethane		83
Trichloroethylene	23	130
Vinyl Chloride	10	20

Source: http://www.pcd.go.th/info_serv/reg_std_airsnd01.html

Thailand also uses an Air Quality Index (AQI) system, most recently updated in November 2018, in addition to the pollutant concentrations, to report air pollution data to the public. The air quality data is updated hourly, and the AQI is also recalculated hourly.

The AQI uses 6 air pollutants for calculation: particulate matter ($PM_{2.5}$ and PM_{10} - 24-hour rolling average), ozone, carbon monoxide (8-hour rolling average), nitrogen dioxide and sulfur dioxide (1-hour average).

The index ranges from 0 to above 201. A value of 0-25 indicates that the air quality is "Excellent", a value of 26-50 is "Satisfactory", a value of 51-100 is "Moderate", a value of 101-200 is "Unhealthy", and a value greater than 201 is considered "Very Unhealthy". The health warnings are given separately for the general public and for sensitive groups. The latter includes children up to age 6, the elderly, pregnant women and patients who are sensitive to air pollution.

Table 3. Thailand AQI classifications.

AQI	Level	Color Code	Description
0-25	Excellent	Blue	Very good air quality; appropriate for outdoor activities and tourism.
26-50	Satisfactory	Green	Good air quality; outdoor activities and tourism possible.
51-100	Moderate	Yellow	*General public:* able to engage in outdoor activities. *Sensitive groups:* If symptoms such as coughing, difficulty breathing, and/or eye irritation are experienced, outdoor activities should be limited.
101-200	Unhealthy	Orange	*General public:* should monitor health. If symptoms such as coughing, difficulty breathing, and/or eye irritation are present, outdoor activities should be limited and/or personal protective equipment should be used as needed. *Sensitive groups:* reduced/minimized outdoor activities and/or use personal protective equipment as needed. If symptoms such as coughing, difficulty breathing, eye irritation, chest pains, headaches, irregular heartbeats, nausea and/or exhaustion are experienced, seek medical assistance.
201^+	Very Unhealthy	Red	Avoid outdoor activities. Avoid areas with poor air quality and/or use personal protective equipment as needed. If any symptoms are experienced, seek medical assistance.

Table 4. AQI classification versus air pollutant concentrations.

AQI (I)	**Concentration of Air Pollutants (X)**					
	$PM_{2.5}$ (µg/m^3)	**PM_{10} (µg/m^3)**	**CO (ppb)**	**O_3 (ppb)**	**NO_2 (ppb)**	**SO_2 (ppb)**
0-25	0-25	0-50	0.0-4.4	0-35	0-60	0-100
26-50	26-37	51-80	4.5-6.4	36-50	61-106	101-200
51-100	38-50	81-120	6.5-9.0	51-70	107-170	201-300
101-200	51-90	121-180	9.1-30.0	71-120	171-340	301-400
201+	91+	181+	30.1+	121+	341+	401+

Other stakeholders involved with Air Quality Management include the Ministry of Energy (MOE), Ministry of Industry (MOI), Office of the Prime Minister, non-profit organizations, and research and academic institutions. All stakeholders were invited to participate in the Conference on Air Quality Assessment for Health and Environmental Policies in Thailand, held at the Miracle Grand Convention Hotel, Bangkok, on November 6th, 2017. The objectives of the conference were to (1) introduce the scope and activities of this UN Environment project and provide a stage for all stakeholders to voice their opinions on the presented information, (2) disseminate information on work being done in Thailand in the management of air quality and health impacts, (3) collect information from all stakeholders on the challenges and limitations related to work being conducted on air quality management, and (4) collect suggestions from all stakeholders for development and/or improvement of work being conducted on management of air quality and assessment of health impacts in Thailand.

As previously mentioned, this project aims to enhance capacity of countries to strengthen and use data and information to assess ambient air quality and support the development and implementation of evidence-based policies on ambient air quality and health. The project aims to address the gaps in knowledge base on ambient air quality and health impacts and connect the two areas, in support of coherent policy-making.

To meet these objectives, this project involves the following key activities (see Figure 2):

1. Analysis of the current situation in Thailand in terms of monitoring environmental air pollutant concentrations and potential health impacts. This includes coordinating with the Pollution Control Department to determine the number and location of monitoring stations around the country, as well as the parameters being monitored at each of the stations. It also includes coordinating with the Ministry of Public Health to determine the system for collecting national health data (morbidity and mortality statistics and cause of disease/death).
2. Selection of representative sites at locations that have both environmental and health monitoring data for air pollutants of concern. Not all environmental monitoring sites are situated in locations close to health monitoring and vice versa, and not all monitoring sites monitor for all air pollutants, e.g. $PM_{2.5}$. Therefore, the selection of sites depends on a few key factors. First, the site must have both environmental and health monitoring data associated with it. Second, the environmental monitoring data must be for air pollutants of interest. Third, the air pollutants of interest would have to also relate to the activities/emission sources for those air pollutants.
3. Request for the environmental and health monitoring data from the relevant authorities. This includes coordinating with the authorities, e.g. Pollution Control Department and Ministry of Public Health, to request the data in a format that can be used for analysis.
4. Statistical analysis. This includes descriptive statistics of the health impacts data and how they relate to concentrations of air pollutants, as well as an analysis of the relative risks for exposure to the air pollutants in the selected locations in Thailand. The relative risk data was also used to calculate economics impacts.
5. Data interpretation.

6. Meeting of stakeholders to discuss results and prepare policy recommendations. A meeting was arranged with key members of the relevant government agencies – Pollution Control Department and Department of Health – to discuss findings and the way forward, particularly policy recommendations that would be in line with the remit and responsibility of the agencies.
7. Preparation of final report for submission to the UN Environment.

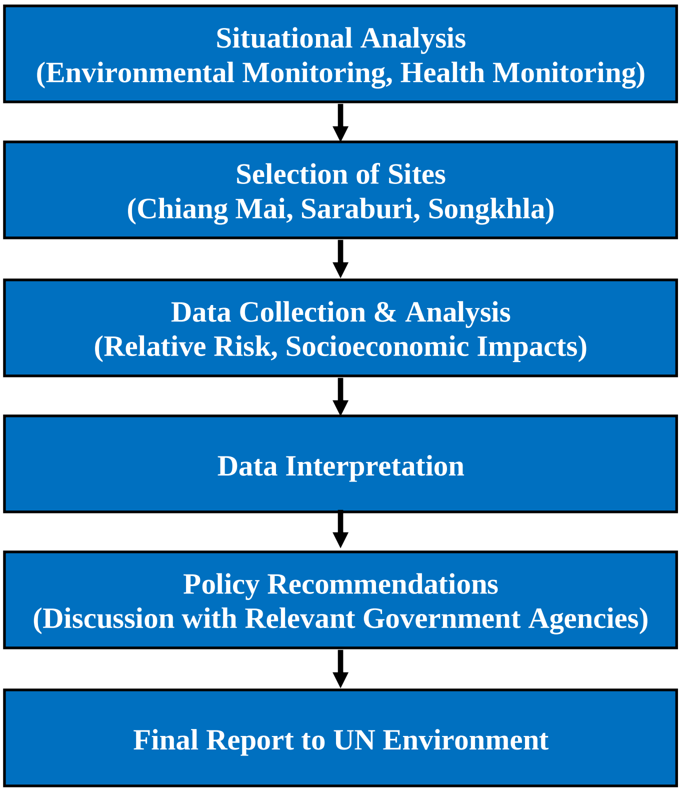

Figure 2. Project Overview.

In this study, the 3 air pollutants of interest are **$PM_{2.5}$, PM_{10}, and ozone.** $PM_{2.5}$ and PM_{10} are key air pollutants of concern globally, with a wealth of literature on health impacts from exposure, while ozone is an air pollutant with continually elevated levels in Thailand (see review in next section).

INTRODUCTION TO AIR POLLUTION AND HEALTH EFFECTS

The term air quality is a broad term that has far-reaching implications. In general, air quality can be significantly impacted by climate (e.g. dry, hot, humid), elevation (e.g. oxygen content), engineering factors such as ventilation (e.g. oxygen and carbon dioxide content), biological factors (e.g. pathogenic airborne micro-organisms), and chemical pollutants (e.g. benzene, particulate matter, etc.). For this project entitled, “Air quality assessments for health and environmental policies in Thailand”, the factor of concern is contamination of air by chemical pollutants.

Chemical pollutants in air can come from local activities, as well as long-range transport, and this is dependent on local weather conditions, geography and man-made structures that can affect air flow and ventilation, as well as physico-chemical properties of the pollutants (e.g. vapor pressure and biodegradability or persistence in environmental media). In general terms, the greater the use of chemicals in local activities, the greater the concentration in air, and the greater the persistence of those chemicals in air, the greater the potential for long-range transport from the original sources.

Health effects of air pollutants is dependent on exposure. Exposure is a term that equates to the amount of chemical that enters into the body through various routes (inhalation, dermal, oral), crosses biological membranes (lung epithelium, skin, gut epithelium), enters into the bloodstream in its parent or metabolized form, reaches the target tissue and elicits an early biological effect that could eventually manifest as disease if not repaired. As such, the amount of internal exposure, i.e. the amount of chemical pollutant(s) that gets into the body and therefore is able to elicit a response, is not the same as the concentration measured in ambient air, external to the exposed individual. This is an important distinction that needs to be made to accurately describe exposure, which can be influenced by age, pre-existing health conditions, behavior, and many other factors. However, as internal exposures are not as easily monitored as levels of pollutants in ambient air, ambient air monitoring is still an important surrogate measure that provides data that is more readily available. Measures of internal exposures, such as biomarkers of exposure (levels in blood and of urinary metabolites), can be invasive (blood collection) and require expertise to conduct the procedures, as well as factor out all confounding factors, e.g. smoking, physical activity, and diet. Still, biomarkers are important in terms of linking ambient exposure levels to health impacts, as well as providing insight into possible mechanisms of disease manifestation.

Air quality has been an important issue for a significant amount of time. The London smog, which lasted for a period of five days in the early 1950s, resulted from trapping of coal-related airborne pollutants by unfavorable weather conditions, and was one of the earliest recorded cases of poor air quality being linked to adverse health impacts, including mortality. Others include similar incidents in a steel town in Pennsylvania, USA and the Meuse Valley in Germany. Since then, air quality has been extensively and scientifically shown to be an important driver of human health.

Apart from environmental effects, such as climate change, with indirect effects on human health (e.g. from expansion of regions with climates conducive to disease vectors, or from severe weather such as draughts and floods), chemical pollutants also have direct health impacts. A variety of different air pollutants have been shown to cause acute and chronic health effects, including debilitating diseases like asthma, premature death, hospital admissions and chronic respiratory disease. Effects include those on the respiratory system, cardiovascular system and central nervous system.

A large body of evidence has been generated over the years to link air pollutant exposures to many adverse health effects, e.g. cardiovascular and respiratory effects. Short-term exposure to particulate matter has been associated with cardiovascular and respiratory mortality (Samet *et al.*, 2000; Samoli *et al.*, 2005). Long-term exposure to fine particulate matter has been linked to increased morality risk (Dockery *et al.*, 1993). Worryingly, there is no evidence for a threshold, below which no effects of $PM_{2.5}$ on mortality are expected to occur (Pope and Dockery 2006; Pope *et al.*, 2002), and the same has been shown for PM_{10} and cardiovascular mortality (Daniels *et al.*, 2000). More recent studies have shown associations between health effects and concentrations of air pollutants at even lower levels than previously seen (Pope *et al.*, 2009; Crouse *et al.*, 2012). Studies in Asia have documented similar adverse health effects of air pollution as studies conducted in Europe and North America. Sharma and colleagues (2004) PM_{10} associated with reduced peak expiratory flow on high pollution days in Kanpur, India. Xu *et al.* (1994) documented increases in daily mortality and hospital admissions with increasing SO_2 and PM levels in Beijing, China. Evidence of a relationship between $PM_{2.5}$ and all-cause, cardiovascular and respiratory mortality in Shanghai, China (Kan *et al.*, 2007). Studies have also established mechanistic bases for the health effects associated with many of these pollutants, e.g. $PM_{2.5}$ is associated with systemic inflammation, oxidative stress and electrical processes of the heart (Brook *et al.*, 2010). This is in addition to evidence linking PM exposure to atherosclerosis (Kunzli *et al.*, 2010; 2005). Cancer is a concern with exposures to carcinogenic air pollutants, including compounds such as benzene and 1,3-butadiene, and there is a large number of publications on this topic (Huff, 2007; Khalade *et al.*, 2010; Landrigan, 1990; Melnick *et al.*, 1993; Snyder, 2012). More recent evidence has also linked air pollutant exposures to various other diseases, including diabetes and neurological effects (Anderson *et al.*, 2012; Brook *et al.*, 2008; Freire *et al.*, 2010; Kramer *et al.*, 2010; Raaschou-Neilsen *et al.*, 2013; Ranft *et al.*, 2009; Ruckerl *et al.*, 2011). Many authoritative reviews on the health effects of air pollution are available (IARC, 2013; IARC, 2016; USEPA, 2013; USEPA, 2009).

In 2017, $PM_{2.5}$ pollution was estimated to contribute to 3 million early deaths, while ozone pollution accounted for nearly half a million early deaths worldwide (Health Effects Institute, 2019). In this same report, age is identified as an important factor in health effects. However, there has been a clear shift from children under 5 being the susceptible population with the highest burden of disease due to air pollution in the 1990s to older populations (60+ years) in 2017. With an estimated >90% of the global population breathing air that is above WHO Air Quality Guidelines, the health situation is a grave concern, particularly for diseases like stroke, heart disease, cancer, chronic obstructive pulmonary disease and acute respiratory infections (Bloemsma *et al.*, 2016; Brunekreef and Hoffmann, 2016; Darrow *et al.*, 2014; Franklin *et al.*, 2015; Hansel *et al.*, 2016; Horne *et al.*, 2018; Katsouyanni and Pershagen, 1997; Lee *et al.*, 2018; Ljungman and Mittelman, 2014; Loomis *et al.*, 2013). The International Agency for Research on Cancer (IARC) classifies outdoor air pollution as carcinogenic to humans (Group 1) and particulate matter in outdoor air pollution as carcinogenic to humans (Group 1) (IARC, 2016).

One of the difficulties in air pollution research, particularly in human studies, is the disconnect between exposure and disease observation. Epidemiological studies assess the association between ambient exposures, controlled for confounding factors, and occurrence of disease. However, ambient exposures do not equate to levels that cross biological membranes (e.g. lung), get into the blood and reach the target tissues. Several important factors, including ambient temperature, volatility of the air pollutant(s), wind velocity and direction, inhalation rate, lipophilicity of the air pollutant(s), and rate of metabolism of the air pollutant(s), play key roles in the concentration of the pollutant(s) that reaches their target tissues. As such, the use of key indicators of internal exposure, e.g. blood levels of pollutants, as well as indicators of early biological changes that are associated with disease manifestation, e.g. DNA damage, are required to be able to provide that important link between ambient exposure and ultimate manifestation of disease. Many studies have been conducted on the use of such indicators, or biomarkers, including recent studies in several developing and developed nations in the areas of inflammation, oxidative stress, and DNA methylation resulting from exposures to air pollutants, including particulate matter, ozone and volatile organic compounds (Dauchet *et al.*, 2018; Guilbert *et al.*, 2019; Ndong Ba *et al.*, 2019; Lee *et al.*, 2019; Li *et al.*., 2019; Rezaei Hachesu *et al.*, 2019; Shakya *et al.*, 2019; Zhang *et al.*, 2019). Published reviews of biomarkers that have been used for studies on air pollution and health impacts are also available (de Oliveira *et al.*., 2014; Desai *et al.*, 2017; Mirowski and Gordon, 2015; Yang *et al.*., 2017). Yet, there are some limitations to the use of biomarkers, including sensitivity, specificity and cost. The analysis and interpretation of biomarker levels also requires expertise, and these are some reasons for the limited research conducted using these indicators, particularly in developing countries. However, as the science of the health impacts of air pollution progresses, it is important for these markers to increasingly be used to help provide a strong link between patterns of exposure to air pollutants and the observed incidence of disease and mortality. The establishment of this clear link would assist in the development of prevention and control measures to reduce the exposure and therefore prevent or reduce disease.

THAILAND SITUATIONAL ASSESSMENT: AIR QUALITY STANDARDS, NATIONAL ACTION PLANS AND RELATED LEGISLATION

Setting Air Quality Standards in Thailand

Setting air quality standards (AQS) in Thailand is done according to the Enhancement and Conservation of National Environmental Quality Act (1992, amended 2018), which specifies that this must involve scientific principles and evidence as the important bases, and must consider the economic, social and technological aspects involved. The Act also gives the National Environmental Board the authority to revise environmental quality standards concomitant with scientific and technological advances, as well as economic and social changes. This can often be done through, for example, National Action Plans.

The Pollution Control Department (PCD), under the Ministry of Natural Resources and Environment (MoNRE), is responsible for drafting environmental quality standards and making recommendations to the national environmental board for consideration and approval. The PCD drafts environmental quality standards by (1) monitoring, collecting and verifying air quality data, according to methods specified by regulations, to be used as baseline/background information for the country towards setting appropriate standards, (2) considering impacts on the environment and human health in setting appropriate standards, and (3) reviewing the latest information available from international organizations in terms of various air quality guidelines, and other developed countries in terms of their national air quality standards, such that air quality standards in Thailand are appropriate and in-line with those guidelines and standards. The PCD also receives input from various governmental agencies and other stakeholders, including all involved committees, in the drafting/revising of environmental quality standards prior to making a recommendation to the national environmental board for consideration and approval.

THAILAND SITUATIONAL ASSESSMENT: AIR MONITORING STATIONS AND HEALTH SURVEILLANCE

Air Monitoring Stations

As of 2018, a total of total of 63 monitoring stations have been established around the country: 28 in central Thailand, which contains the capital – Bangkok; 15 in the North, which suffers from haze from open burning; 11 in the East, which is the important industrial zone; 6 in the South, which is affected by transboundary haze; and 3 in the North-East, which is an important agricultural area). The monitoring stations conduct two types of monitoring: automated continuous monitoring, e.g. for $PM_{2.5}$, PM_{10}, and manual non-continuous monitoring, e.g. for benzene and other volatile organic compounds (VOCs).

Health Surveillance

The Ministry of Public Health (MOPH) is the responsible national agency that oversees issues related to health. However, healthcare is administered at the regional, provincial (Provincial Health Office), district (District Health Office/District Hospitals) and sub-district levels (Sub-district Health Promotion Hospitals). Health data for individuals is collected and checked at the sub-district levels before being sent to the district level where the data is cleansed and verified. The data is then sent to the provincial level to be processed and analyzed, before being aggregated at the regional level and the aggregated data is quality-checked and analyzed at the national level. The health data that is collected can be classified into 3 types: health resources (human resources, health facilities, supplies and equipment, and financial resources), health services (health promotion, immunization, treatment), and health status (vital statistics, mortality and morbidity). Health status is categorized according to the International Statistical Classification of Diseases and Related Health Problems, 10th revision (ICD10).

The ICD10 classification is a medical classification list by the World Health Organization.

Table 5. ICD10 classification.

Code	Corresponding Health Classification
A00-B99	Certain infectious and parasitic diseases
C00-D48	Neoplasms
D50-D89	Diseases of the blood and blood-forming organs and certain disorders of the immune mechanism
E00-E90	Endocrine, nutritional and metabolic diseases
F00-F99	Mental and behavioral disorders
G00-G99	Diseases of the nervous system
H00-H59	Diseases of the eye and adnexa
H60-H95	Diseases of the ear and mastoid process

Code	Corresponding Health Classification
I00-I99	Diseases of the circulatory system
J00-J99	Diseases of the respiratory system
K00-K93	Diseases of the digestive system
L00-L99	Diseases of the skin and subcutaneous tissue
M00-M99	Diseases of the musculoskeletal system and connective tissue
N00-N99	Diseases of the genitourinary system
O00-O99	Pregnancy, childbirth and the puerperium
P00-P99	Certain conditions originating in the perinatal period
Q00-Q99	Congenital malformations, deformations and chromosomal abnormalities
R00-R99	Symptoms, signs and abnormal clinical; and laboratory findings, not elsewhere classified
S00-T98	Injury, poisoning and certain other consequences of external causes
V01-Y98	External causes of morbidity and mortality
Z00-Z99	Factors influencing health status and contact with health services
U00-U85	Codes for special purposes

STUDY DESIGN AND METHODOLOGY

The information considered in this report comes from two main sources. First is the air quality monitoring data from stations in 5 representative provinces from five geographical regions in Thailand: **Chiang Mai (north), Khon Kaen (northeast), Rayong (east), Saraburi (central) and Songkhla (south).** These stations were selected from the aforementioned 63 stations as they monitor all the pollutants of interest for this study. The key pollutants of concern are $PM_{2.5}$, PM_{10}, and ozone. Second, is the health effects data provided by hospitals under the jurisdiction of the Ministry of Public Health (MoPH), categorized according to ICD10 as previously described. The health effects of concern selected for analysis in this study are cancer (ICD-10 classification C), diseases of the eye (ICD-10 classification H), cardiovascular diseases (ICD-10 classification I) and respiratory diseases (ICD-10 classification J).

Table 6. ICD-10 and corresponding health classification.

Code	Corresponding Health Classification
C00-D48	Neoplasms, including: • C30-C39 - Malignant neoplasms of respiratory and intrathoracic organs • C81-C96 - Malignant neoplasms of lymphoid, hematopoietic and related tissue
H00-H59	Diseases of the eye and adnexa, including: • H10-H11 - Disorders of conjunctiva • H15-H22 - Disorders of sclera, cornea, iris and ciliary body • H40-H42 - Glaucoma
I00-I99	Diseases of the circulatory system, including: • I10-I16 - Hypertensive diseases • I20-I25 - Ischemic heart diseases • I26-I28 - Pulmonary heart disease and diseases of pulmonary circulation • I30-I52 - Other forms of heart disease • I60-I69 - Cerebrovascular diseases • I70-I79 - Diseases of arteries, arterioles and capillaries • I80-I89 - Diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified • I95-I99 - Other and unspecified disorders of the circulatory system
J00-J99	Diseases of the respiratory system, including: • J00-J06 - Acute upper respiratory infections • J09-J18 - Influenza and pneumonia • J20-J22 - Other acute lower respiratory infections • J30-J39 - Other diseases of the upper respiratory tract • J40-J47 - Chronic lower respiratory diseases • J60-J70 - Lung diseases due to external agents • J80-J84 - Other respiratory diseases principally affecting the interstitium

Code	Corresponding Health Classification
	• J85-J86 - Suppurative and necrotic conditions of the lower respiratory tract • J90-J94 - Other diseases of the pleura • J95 - Intraoperative and postprocedural complications and disorders of respiratory system, not elsewhere classified • J96-J99 - Other diseases of the respiratory system

Within the classification of diseases of the respiratory system, the data sub-set that was used for descriptive statistical analysis was J00-J06: acute upper respiratory infections.

ANALYSIS OF ASSOCIATIONS BETWEEN AIR QUALITY AND HEALTH EFFECTS DATA

Descriptive Statistics and Regression Analysis

Two sets of data were analyzed. The first set consisted of air monitoring data for $PM_{2.5}$, PM_{10} and ozone from 9 districts of 5 provinces (Saraburi - SRI, Rayong - RYG, Khon Kaen - KKN, Chiang Mai - CMI, and Songkhla - SKA). The data set was collected from January 1, 2014 to December 31, 2017 (1,460 days) and contained 13,140 data points. The second set consisted of health data from patients who received health care service at hospitals in 9 districts of the 5 provinces. These patients were separated into 13 age groups (0-4, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-120 years). The health effects data used in this analysis were selected for their associations to air quality; that is, the acute upper respiratory infections (ICD10 code J00-J06). This data set included data from 772,357 patients.

Analysis of Relative Risks for People Exposed to $PM_{2.5}$, PM_{10} or Ozone

Data analysis

Raw health data provided by the Ministry of Public Health were in the form of anonymized individual out-patient department (OPD) records divided into 13 age groups: 0-4, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, and 60+ years, for each ICD-10 health effects code of interest: H10-H11, H15-H22, H40-H42, I10-I16, I20-I25, I26-I28, I30-I52, I60-I69, I70-I79, I80-I89, I95-I99, J00-J06, J09-J18, J20-J22, J30-J39, J40-J47, J60-J70, J80-J86, J90-J94, J95, and J96-J99. The data were consolidated into a data matrix containing the number of OPD records for each ICD-10 classification for each district of the provinces of interest (**Chiang Mai, Saraburi, and Songkhla**).

The three provinces were selected for potentially different exposure scenarios (sources, activities) and levels. Chiang Mai in the norther part of Thailand is known to be affected by air pollutants from open burning and geological features (mountains) that affect air flow and trap pollutants. Saraburi in the central part of the country is known to have stone mining and processing activities that can be important sources of pollutants. Songkhla in the southern part of Thailand was chosen for being a hypothetically less-polluted area.

For air pollution data retrieved from the Pollution Control Department, the raw data were in the form of hourly measurements of the 3 pollutants of interest ($PM_{2.5}$, PM_{10}, and O_3) from air monitoring stations in the various provinces. Unfortunately, blocks of data were missing for certain pollutants at certain time points due to various reasons, e.g. power loss to the monitoring equipment. No missing data imputation was performed on both the health and air pollution data as the blocks of missing data were too large. All data handling and analysis were performed in the R statistical environment version 3.5.0 software package.

Descriptive analysis

Line-and-bar plots for weekly pollutant levels and weekly OPD patient numbers were generated. The weekly pollution levels were calculated as follows: first, median values were calculated for each day (24-hour period) and then for each week (7-day period). The final values expressed in the line plots are weekly median pollutant values from the air monitoring stations. The weekly OPD patient numbers are the sum of OPD patient numbers across the same 7-day period as the collected pollutant data. Each bar represents the OPD patient numbers for each week.

Statistical analysis

The generalized linear model (GLM) was used for data analysis with the Poisson link function. The model is a simple regression model with single pollutants as predictors and the number of OPD admissions as the response variable. Missing values in the data were omitted in the calculations. Seven-day median values of the daily median values for each pollutant were used as the predictor, and the seven-day total OPD admissions were used as the predictor and response variables, respectively. The model did not correct for seasonal trends and did not include any interaction terms or potential confounding factors, such as humidity and wind speed, except for weekend trends (i.e. five-day and two-day intervals). The relative risks of 10-unit points (i.e. 10 $\mu g/m^3$ for $PM_{2.5}$ and PM_{10}) calculated from the exponent of β coefficient estimates for each pollutant, along with lower and upper limits of the estimates, were used to create forest plots that compare the relative risks for the three different sites for each ICD-10 disease category.

Disability-Adjusted Life Years (DALYs)

To measure the impact that diseases have on the lives of people, the World Health Organization (WHO) uses a metric called the Disability-Adjusted Life Year (DALY) to quantify the burden of disease. The DALY is the sum of two components:

DALY = YLL + YLD;

where YLL is "years of life lost", which is a measure of the mortality of the diseases, and YLD is "years lost due to disability", which measures the burden of living with diseases or disabilities. According to the latest version of the Global Burden of Disease study (2015) by WHO, the YLL is calculated by:

YLL = N x L;

where N is the number of deaths due to the disease-associated health conditions, and L is standard life expectancy at the age of death (expectancy – age at death). YLD is calculated by:

YLD = P x DW;

where P is the number of prevalent cases of the disease, and DW is the disability weight of the disease. The disability weight of the diseases used in this study were taken directly from the

WHO data repository for the Global Burden of Disease study. The number of cases of each ICD-10 for each of the **3 districts of interest (Muang Chiang Mai district – Chiang Mai Province, Chaloem Pra Kiat district – Saraburi Province, and Hat Yai district – Songkhla Province)** were collected from the 2012-2016 OPD data provided by the health statistics unit of the Ministry of Public Health of Thailand. Since we do not know the specific disease of each individual case, we cannot directly apply the disability weight to each specific case, and therefore we can only calculate YLD and YLL in terms of lower and upper limits based on the lowest and highest disability weights for each ICD-10 category (i.e. a range). After the YLD and YLL are calculated for each ICD-10 term, all YLDs and YLLs in the same ICD-10 categories (i.e. cancer, eye, circulatory and respiratory diseases) were summed up. The resulting YLDs and YLLs were finally corrected for population size in each district and reported as per 1,000 and per 100,000 of the respective populations.

Health impact assessment of separate pollutants

A health impact function was used to assess the effect of each pollutant on the excess number of patients by disease categories of interest. The health impact function is expressed as follows:

$$\Delta E_{morbid} = \left[1 - e^{-\beta(C_a - C_0)}\right] \times I_r \times E_{pop}$$

where ΔE_{morbid} is the estimated excess number of patients incurred by exposure to an excess amount of pollutant of interest; E_{pop} is the estimated population of the district of interest; β is the exposure-response coefficient (ERC); C_a is the annual average concentration of the pollutant; C_0 is the WHO air quality guideline value for the pollutant; and I_r is the baseline incidence rate of a health outcome category of interest. The ERC can be inferred from the relative risk of the disease category that was calculated previously:

$$RR = e^{\beta \Delta C}$$

where RR is relative risk of the disease category of interest, and ΔC is the excess pollutant units that were used in the RR calculations, which in this case is 10-units. The resultant number is an estimate of the excess number of people affected by an ICD-10 disease classification from exposure to the pollutants of interest.

Health Economic Impact Assessment

Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE) (Sacks *et al.*., 2018) is a Windows operating system-based software that calculates health impacts from air pollution based on air monitoring data and statistical models. In this analysis, the data from two provinces, Chiang Mai and Saraburi, were used in the analysis because these two provinces have data from more than one air monitoring stations available. The year 2017 were chosen for the analysis because PM_{10} and $PM_{2.5}$ data of that year were the most complete compared to other years. Population data for every age from 0-120 years of the two provinces in the year 2017 were retrieved from the website of Bureau of Registration Administration, Department of Provincial Administration, Ministry of Interior, Thailand, on 8 October 2018. Pollutant monitoring data were provided by Pollution Control Department (PCD), Ministry of Natural Resources and Environment, Thailand. Beta (relative risk) and Parameter 1 (standard error) values of mortality from respiratory diseases, cardiovascular diseases and cancer associated with pollutants were calculated according to previously described methods for PM_{10} and $PM_{2.5}$ (Pinichka *et al.*, 2017) and ozone (Guo *et al.*, 2014). Mortality data were provided by the Health Impact Assessment Division, Department of Health, Ministry of Public Health, Thailand. The Beta and Parameter 1 (standard error) are parts of the following health impact function [1]:

$$HIF = \left(1 - \frac{1}{e^{\beta * \Delta Q}}\right) * incidence * population$$

Where:

- ΔQ is the excess pollutant level of interest
- β is relative risk of the pollutant
- *incidence* is the incidence rate of the disease group of interest based on the number of mortalities and populations in the respective provinces
- *population* is the total number of people in the respective province in the year 2017

In order to calculate the economic valuation of pollutant reduction, Air Quality Surfaces have to be created. The grid creation method used in this analysis is the Monitor Rollback method with Percentage Rollback used to calculate the benefits from pollutant reductions of 25%, 50%, and 75% of historical levels, and Rollback to Standard used to calculate the benefit from pollutant reduction to the WHO Air Quality Guideline levels. Population dataset for the analysis is in the format of 5-year interval groups, starting from 0 to 59 years with the final group starting from 60 years onwards. Aggregation, Pooling, and Valuation (APV) configuration for this analysis is as follows:

Aggregation level: Borders of the province was used as aggregation level.

Pooling: Sum Independent pooling was used for all the disease groups.

Valuation: The Value per Statistical Life (VSL) method by US EPA was used.

Value per Statistical Life (VSL) is the value of an avoided premature mortality based on the US income level in a certain reference year, and the value is then adjusted for the year of interest. The VSL estimate for Thailand in the year 2017 was used in this analysis [4], which can be calculated as follows:

$$VSL_{Thailand,2017} = VSL_{Thailand,1998} * \left(\frac{Y_{Thailand,2017}}{Y_{Thailand,1998}}\right)^{\varepsilon} * PPP_{1998} * \frac{CPI_{Thailand,2017}}{CPI_{Thailand,1998}}$$

where:

- $VSL_{Thailand,2017}$ is the VSL value for Thailand in 2017 (in Thai Baht) at 2017 Thai income levels
- $VSL_{Thailand,1998}$ is the VSL value for Thailand in 1998 (in US dollars)

- Y is the per capita GDP of the specified country in the specified year, expressed in constant international (PPP-adjusted) dollars
- ε is the income elasticity of the VSL; the BenMAP-CE default is 0.4
- PPP_{1998} is the Purchasing Power Parity index in 1998 (in Thai Baht per international dollar)
- $CPI_{Thailand}$ is the consumer price index in Thailand in the specified years

In this analysis, BenMAP-CE v.1.4.14.1 was used to calculate the VSL in the year 2017 in Chiang Mai and Saraburi provinces. All VSL results are in Thai Baht. All the files required in the calculation are provided in the appendix.

RESULTS

[see Appendix for forest plots showing relative risk]

This results section is organized into (a) the descriptive statistics, which describe the study subjects and hospital admissions data, (b) the significant relative risk findings by province, (c) the significant relative risk findings by pollutant, (d) the calculation of disability-adjusted life years associated with exposure to the air pollutants of interest, and (e) the results from the BenMAP software calculations of economic impacts of health effects associated with exposure to the pollutants of interest, as well as the potential benefits from reduction in exposure levels.

Descriptive Statistics

Figure 3 shows the number of patients per day at each of the 9 district hospitals in 5 provinces (Chiang Mai, Khon Kaen, Rayong, Saraburi and Songkhla).

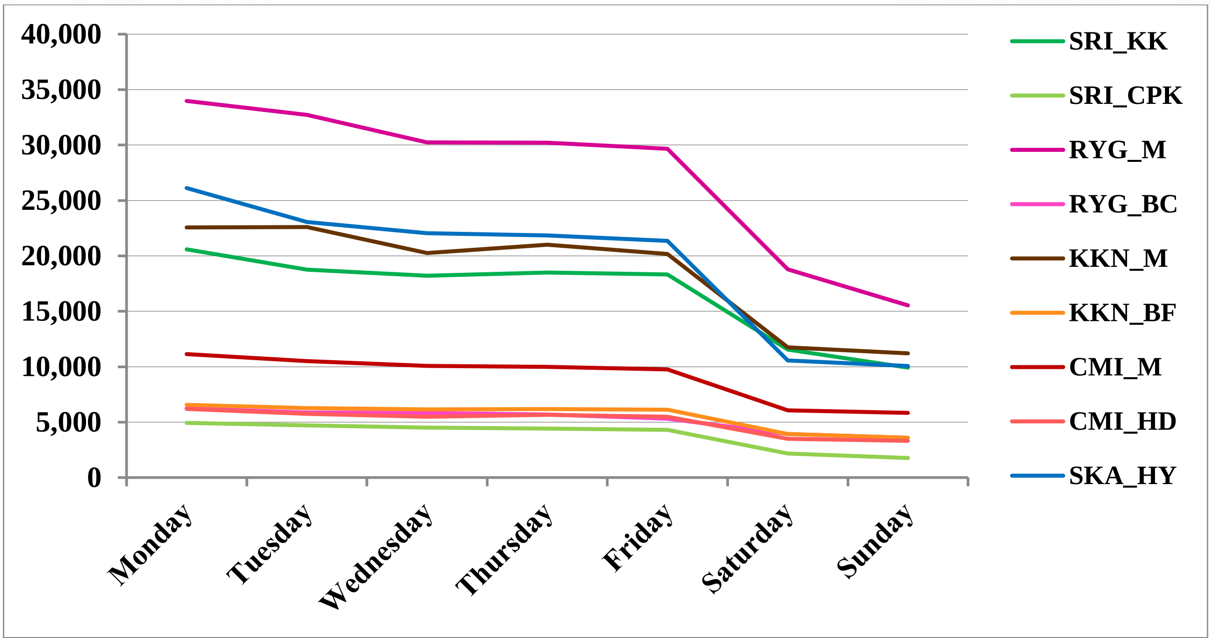

Figure 3. Number of patients by day of week (per district hospital).

SRI_KK = Saraburi province – Kaeng Khoi district, SRI_CPK = Saraburi province – Chaloem Phra Kiat district, RYG_M = Rayong province – Mueang district, RYG_BC = Rayong province – Ban Chang district, KKN_M = Khon Kaen province – Mueang district, KKN_BF = Khon Kaen province – Ban Fang district, CMI_M = Chiang Mai province – Mueang district, CMI_HD = Chiang Mai province – Hang Dong district, and SKA_HY = Songkhla province – Hat Yai district.

Most of the acute upper respiratory infection patients went to receive treatment at the respective hospitals on Mondays (17.6%), with the least number of patients going to receive treatment on Sundays (9.3%).

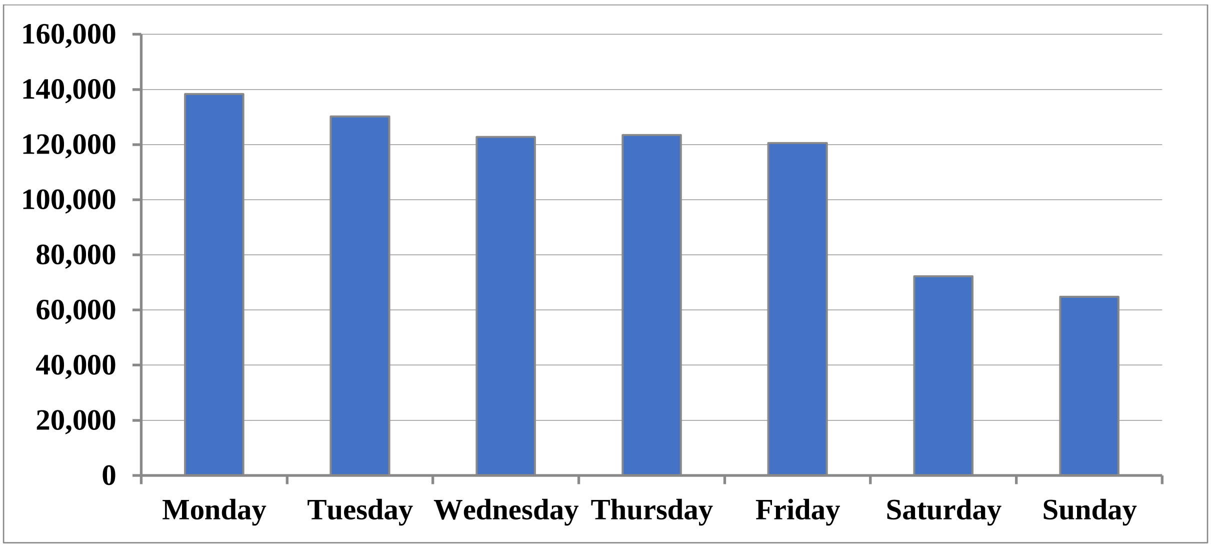

Figure 4. Number of patients by day of week (all district hospitals).

Figure 4 shows the total number of patients per day at all nine district hospitals. The majority of patients were in the 0-4 years age group (26.8%), followed by the 5-9 years age group (13.5%) and the 60+ years age group (7.9%). Figure 5 shows the number of patients by age group at each of the 9 district hospitals. Figure 6 shows the total number of patients per age group at all district hospitals. The greatest number of patients were seen at the low end of the age range (0-4 and 5-9) and the highest end of the age range (60+).

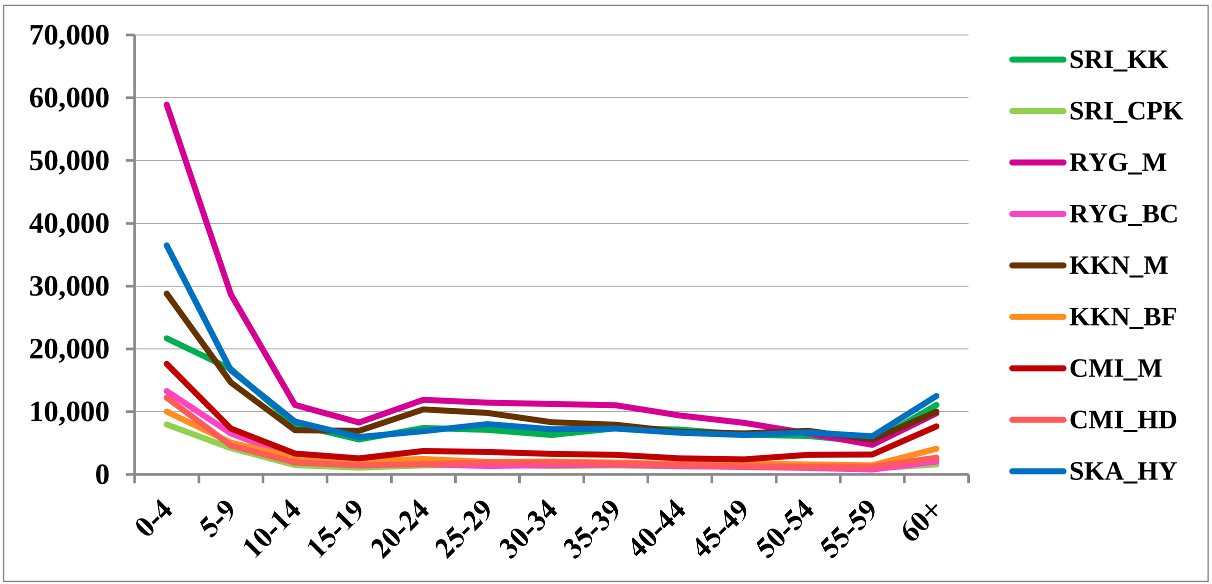

Figure 5. Number of patients by age group (by district hospital).

SRI_KK = Saraburi province – Kaeng Khoi district, SRI_CPK = Saraburi province – Chaloem Phra Kiat district, RYG_M = Rayong province – Mueang district, RYG_BC = Rayong province – Ban Chang district, KKN_M = Khon Kaen province – Mueang district, KKN_BF = Khon Kaen province – Ban Fang district, CMI_M = Chiang Mai province – Mueang district, CMI_HD = Chiang Mai province – Hang Dong district, and SKA_HY = Songkhla province – Hat Yai district.

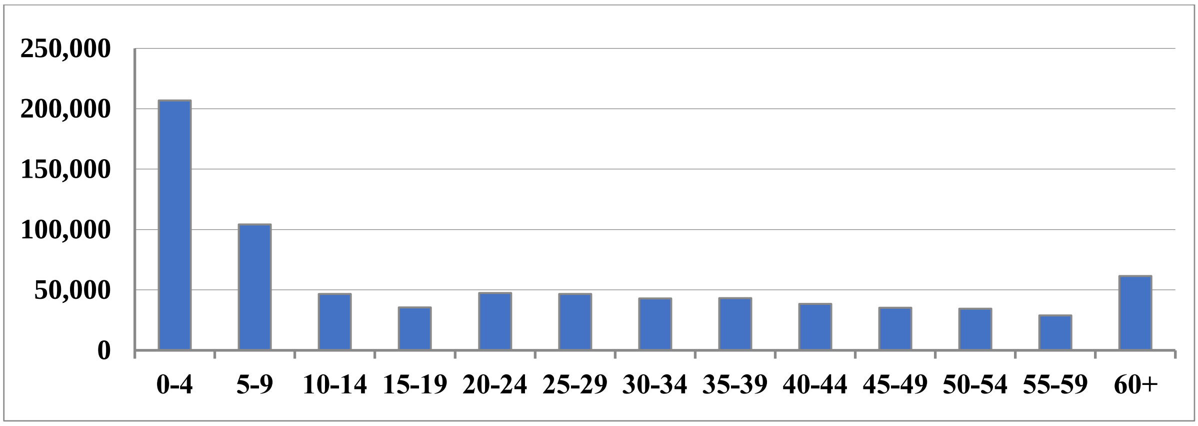

Figure 6. Number of patients by age group (all district hospitals).

In terms of the air quality in the vicinity of the 9 hospitals, 49.5% were in areas with concentrations of $PM_{2.5}$ ranging from 12.1 to 35.4 µg/m^3, followed by 22.1% in areas with up to but not exceeding 12.0 µg/m^3. For PM_{10}, 69.1% of the hospitals were situated in areas with concentrations ranging up to but not exceeding 54 µg/m^3, and 28.5% in areas ranging in PM_{10} concentrations between 55 and 154 µg/m^3. As for ozone, 98.9% of the hospitals were situated in areas with concentrations less than 0.054 PPM. For reference, the Thai national air quality standards are 120 µg/m^3 (PM_{10}, 24-hr), 50 µg/m^3 (PM_{10}, annual), 50 µg/m^3 ($PM_{2.5}$, 24-hr), 25 µg/m^3 ($PM_{2.5}$, annual) and 0.07 PPM (ozone, 8-hr).

The following analysis of number of patients per air pollutant levels was done according to two air quality classification schemes: the USEPA scheme and the updated Thai air quality classification scheme.

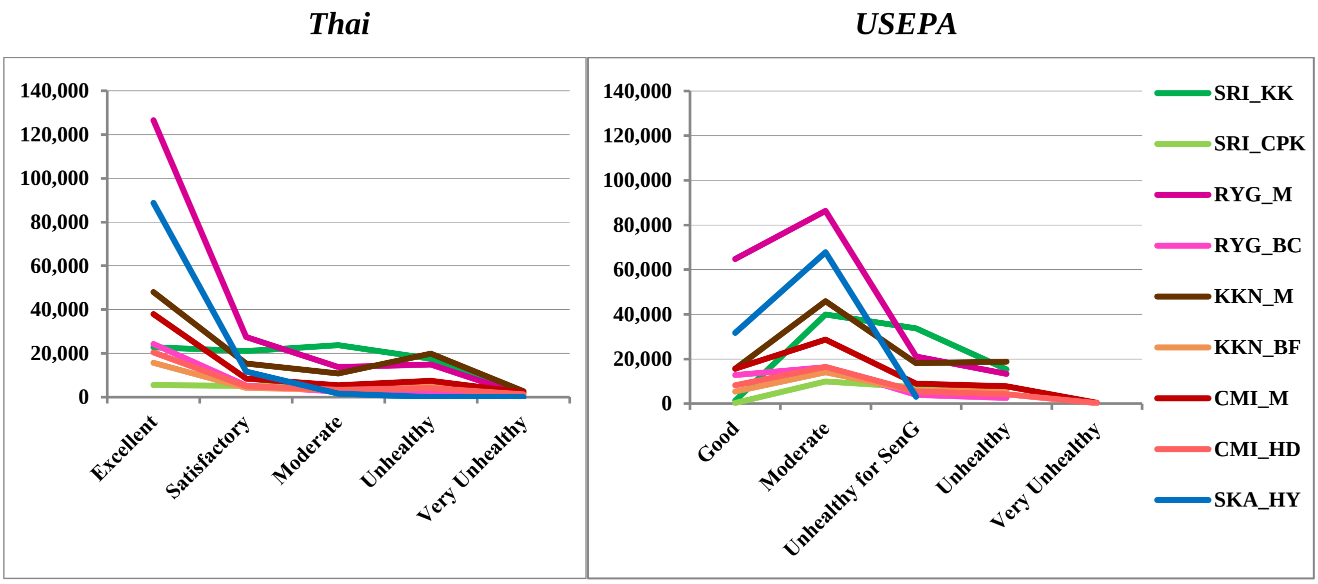

Figure 7. Number of patients by $PM_{2.5}$ level classification (per district hospital).

SRI_KK = Saraburi province – Kaeng Khoi district, SRI_CPK = Saraburi province – Chaloem Phra Kiat district, RYG_M = Rayong province – Mueang district, RYG_BC = Rayong province – Ban Chang district, KKN_M = Khon Kaen province – Mueang district, KKN_BF = Khon Kaen province – Ban Fang district, CMI_M = Chiang Mai province – Mueang district, CMI_HD = Chiang Mai province – Hang Dong district, and SKA_HY = Songkhla province – Hat Yai district.

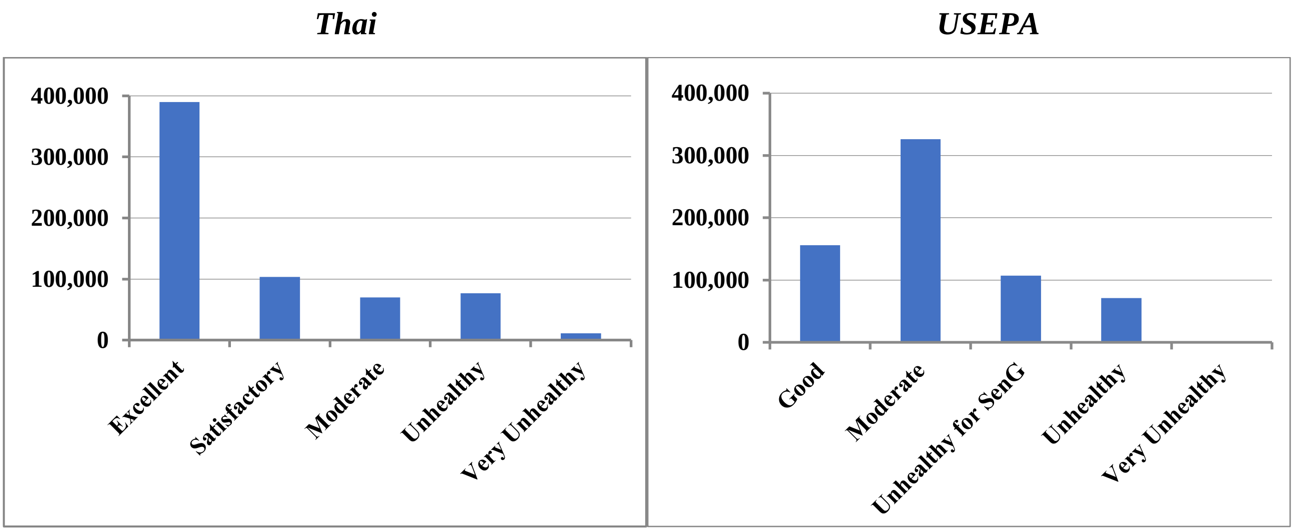

Figure 8. Number of patients by $PM_{2.5}$ level classification (all district hospitals).

Table 7. Comparison of Thai and US EPA $PM_{2.5}$ air quality classifications (units = $\mu g/m^3$).

Level	Thai AQI Standard		US EPA Standard		Level
	Range	Difference	Difference	Range	
Excellent	0-25	25	12	0-12	Good
Satisfactory	26-37	11	23.3	12.1-35.4	Moderate
Moderate	38-50	12	19.9	35.5-55.4	Unhealthy for Sensitive Groups
Unhealthy	51-90	39	94.9	55.5-150.4	Unhealthy
Very Unhealthy	> 91	-	99.9	150.5-250.4	Very Unhealthy
			249.9	250.5-500.4	Hazardous

The data presented in Figures 7-8 and Table 7 show that with the US EPA standard, most patients were in the “Moderate” level of $PM_{2.5}$, whereas according to the Thai AQI standard, patients were mostly in the “Excellent” air quality classification. Saraburi seemed to be the most affected, where patients were distributed most equally among each $PM_{2.5}$ classification. Khon Kaen also had a lot of patients in the “Unhealthy” $PM_{2.5}$ classification.

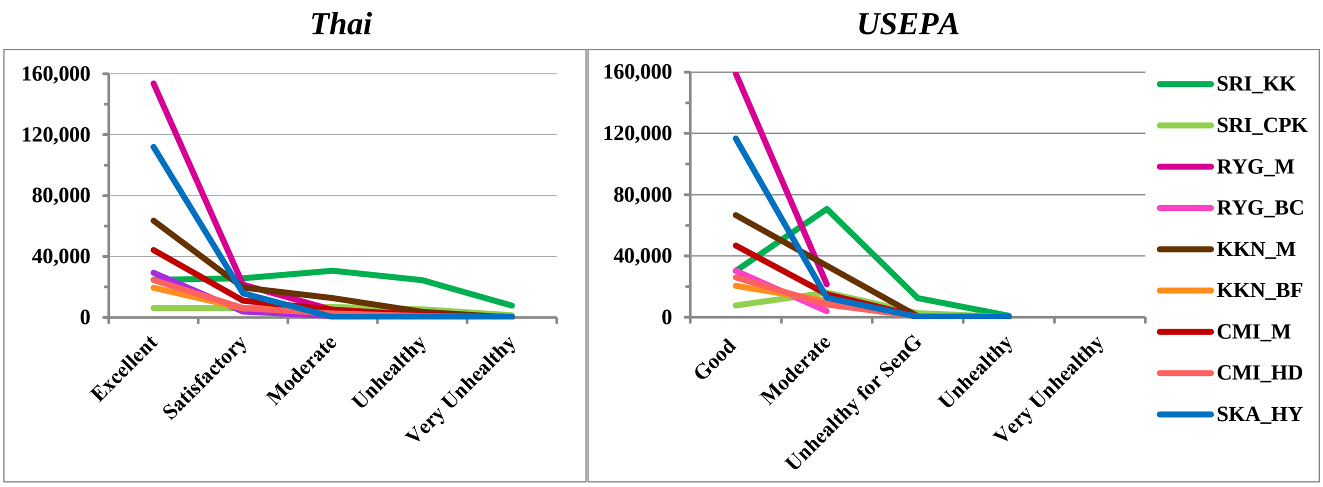

Figure 9. Number of patients by PM_{10} levels (per district hospital).

SRI_KK = Saraburi province – Kaeng Khoi district, SRI_CPK = Saraburi province – Chaloem Phra Kiat district, RYG_M = Rayong province – Mueang district, RYG_BC = Rayong province – Ban Chang district, KKN_M = Khon Kaen province – Mueang district, KKN_BF = Khon Kaen province – Ban Fang district, CMI_M = Chiang Mai province – Mueang district, CMI_HD = Chiang Mai province – Hang Dong district, and SKA_HY = Songkhla province – Hat Yai district.

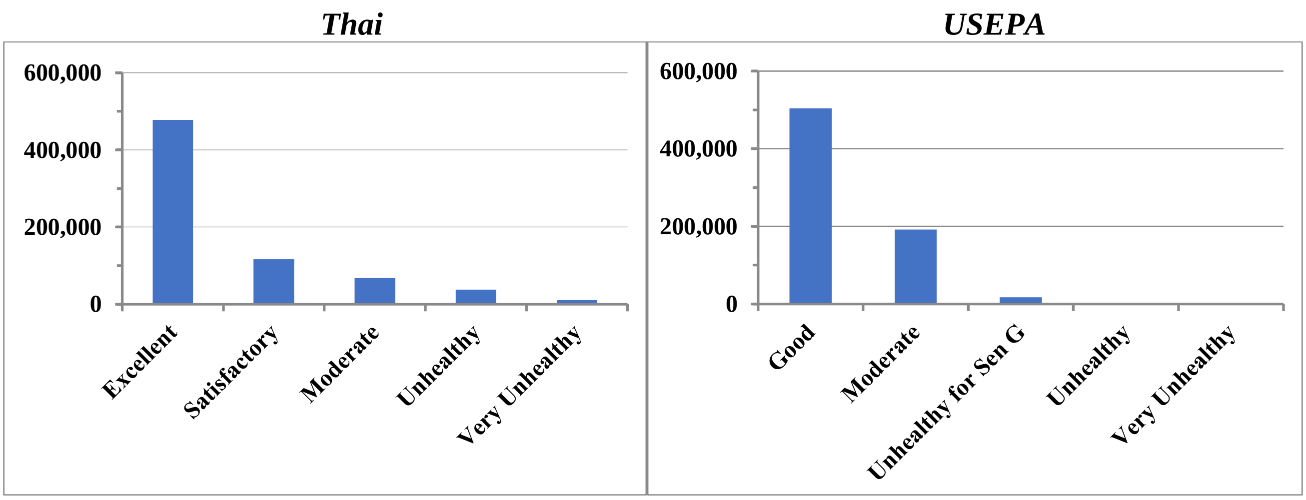

Figure 10. Number of patients by PM_{10} classification (all district hospitals).

Table 8. Comparison of Thai and US EPA PM_{10} air quality classifications (units = $\mu g/m^3$).

Level	Thai AQI Standard		US EPA Standard		Level
	Range	Difference	Difference	Range	
Excellent	0-50	50	54	0-54	Good
Satisfactory	51-80	29	99	55-154	Moderate
Moderate	81-120	39	99	155-254	Unhealthy for Sensitive Groups
Unhealthy	121-180	59	99	255-354	Unhealthy
Very Unhealthy	> 181	-	69	355-424	Very Unhealthy
			179	425-604	Hazardous

The data presented in Figures 9-10 and Table 8 show that Saraburi had the greatest number of patients in the poorer air quality classifications as it pertains to PM_{10}.

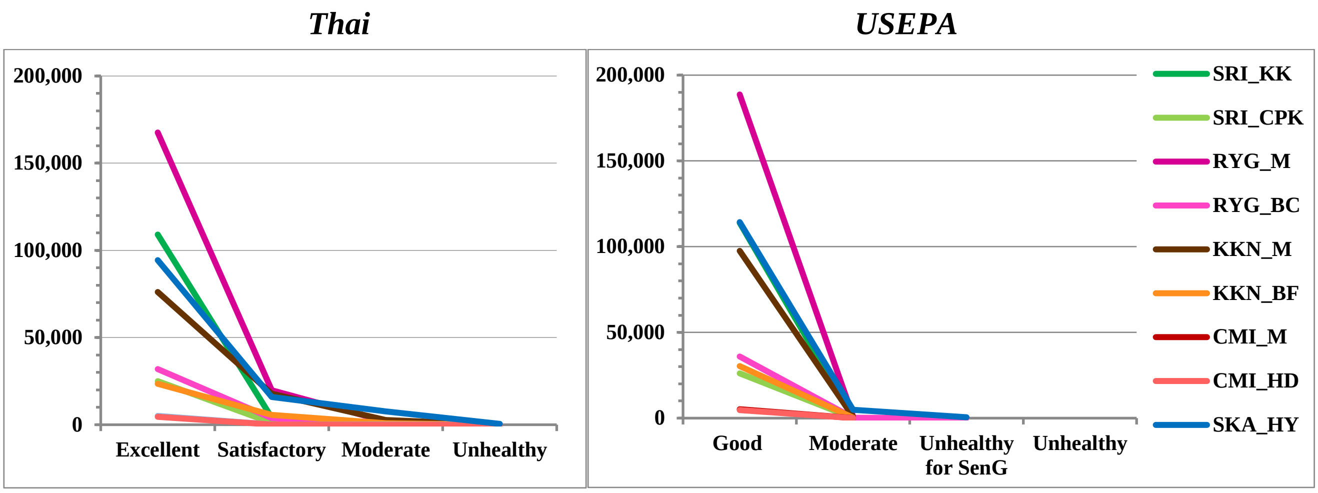

Figure 11. Number of patients by ozone levels (per district hospital).

SRI_KK = Saraburi province – Kaeng Khoi district, SRI_CPK = Saraburi province – Chaloem Phra Kiat district, RYG_M = Rayong province – Mueang district, RYG_BC = Rayong province – Ban Chang district, KKN_M = Khon Kaen province – Mueang district, KKN_BF = Khon Kaen province – Ban Fang district, CMI_M = Chiang Mai province – Mueang district, CMI_HD = Chiang Mai province – Hang Dong district, and SKA_HY = Songkhla province – Hat Yai district.

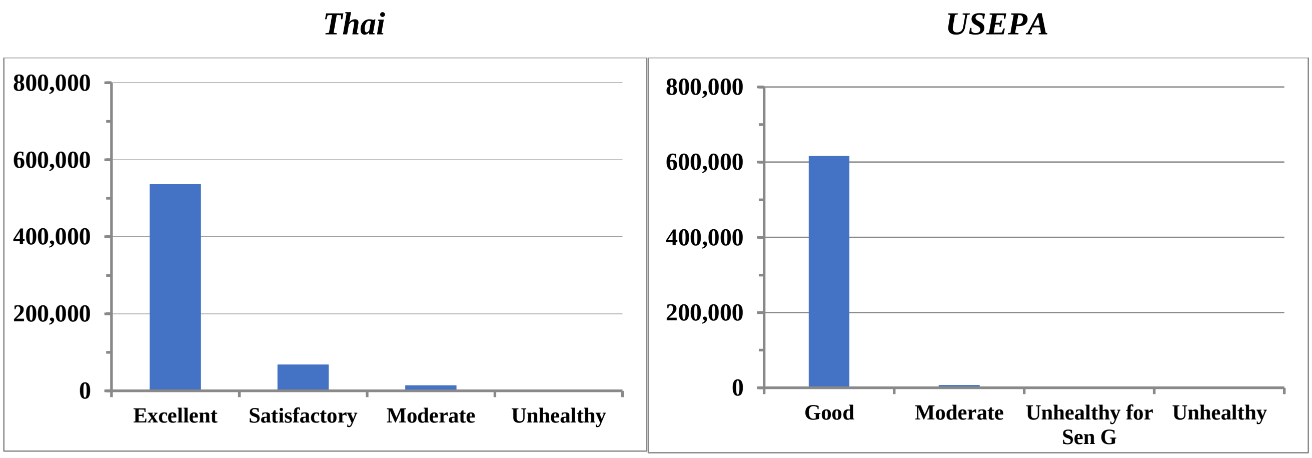

Figure 12. Number of patients by ozone classification (all district hospitals).

Table 9. Comparison of Thai and US EPA O_3 air quality classifications (units = PPM).

Level	Thai AQI Standard		US EPA Standard		Level
	Range	Difference	Difference	Range	
Excellent	0-0.035	0.035	0.054	0-0.054	Good
Satisfactory	0.036-0.050	0.015	0.015	0.055-0.070	Moderate
Moderate	0.051-0.070	0.019	0.014	0.071-0.085	Unhealthy for sensitive groups
Unhealthy	0.071-0.120	0.049	0.019	0.086-0.105	Unhealthy
Very unhealthy	> 0.121	-	0.094	0.106-0.200	Very unhealthy

The data presented in Figures 11-12 and Table 9 show that the Thai AQI standard for ozone is stricter than that of the US EPA and likely contributed to a larger number of patients in the Thai “Moderate” category than “Unhealthy for Sensitive group” classification of the US EPA.

Relative Risk - Significant Findings by Province

Chiang Mai

Age	Cancer			Eye diseases			Cardiovascular diseases			Respiratory diseases			Total / Age group
0 - 4				1.06	1.05							1.15	**3**
5 - 9			4.72						1.26			1.20	**3**
10 - 14												1.16	**1**
15 - 19						1.46			1.29			1.18	**3**
20 - 24	1.21	1.21							1.49			1.32	**4**
25 - 29						1.21			1.54	1.02	1.02	1.29	**5**
30 - 34			2.13					1.01	1.51	1.01	1.02	1.29	**6**
35 - 39						1.17		1.02	1.48	1.01	1.01	1.23	**6**
40 - 44								1.02	1.51	1.01	1.02	1.31	**5**
45 - 49						1.34		1.02	1.50	1.03	1.03	1.31	**6**
50 - 54	1.03	1.03	1.57			1.11	1.01	1.02	1.44	1.02	1.02	1.18	**10**
55 - 59			1.97					1.02	1.46	1.02	1.02	1.31	**6**
60+			1.40			1.12		1.01	1.51		1.01	1.28	**6**
Category Total / Pollutant	**2**	**2**	**5**	**1**	**1**	**6**	**1**	**7**	**11**	**7**	**8**	**13**	**Grand Total**
Category Total	**9**			**8**			**19**			**28**			**64**

$PM_{2.5}$ **PM_{10}** **O_3**

Table 10. Significant observations (RR>1.0) by age group in Chiang Mai.

There was a total of 64 significant observations (RR>1.0) in the Chiang Mai data when ICD-10 data were grouped according to disease classification (cancer, eye diseases, cardiovascular diseases, and respiratory diseases): 11 associated with $PM_{2.5}$ (17.19%), 18 associated with PM_{10} (28.13%), and 35 associated with ozone (54.69%). The greatest number of significant observations were in the 50-54 years (15.63%) age group, followed by the 30-34 years, 35-39 years, 45-49 years, 55-59 years, and 60+ years (each 9.38%) age groups. The greatest number of significant observations were seen for respiratory effects (43.75%). When looking at the relative risk values, the relationships between cancer and ozone in the 5-9 years age group (4.72) and 30-34 age group (2.13) stand out as being quite large and may require a closer assessment.

Table 11. Significant observations (RR>1.0) by ICD-10 in Chiang Mai.

Chiang Mai

	ICD-10 code	0 - 4			5 - 9			10 - 14			15 - 19			20 - 24			25 - 29			30 - 34			35 - 39			40 - 44			45 - 49			50 - 54			55 - 59			60+			Code Total	Category Total
		$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3		
Cancer	C30-C39																																				2.32			1.34	2	5
	C81-C96						8.86							1.49																										1.91	3	
Eye diseases	H10-H11	1.06	1.05																																					1.15	3	6
	H15-H22																					2.29																			1	
	H40-H42																														1.80									1.11	2	
Cardiovascular Diseases	I10-I16																					1.24			1.25		1.01	1.24		1.01	1.27		1.01	1.22		1.01	1.21			1.28	11	32
	I20-I25																											1.85			1.56						1.66		1.01	1.48	5	
	I26-I28																																								0	
	I30-I52																		1.81									1.46									1.21			1.25	4	
	I60-69						10.44			14.88																		1.53			1.30						1.32			1.16	6	
	I70-I79																																				4.58				1	
	I80-I89																											1.56			1.42			1.45						1.27	4	
	I95-I99																					29.61																			1	
Respiratory diseases	J00-J06			1.14			1.20			1.14			1.21			1.31	1.02	1.02	1.28		1.02	1.35	1.02	1.02	1.25	1.02	1.03	1.24	1.04	1.04	1.33	1.02	1.02	1.24	1.03	1.03	1.30	1.01	1.02	1.38	28	69
	J09-J18			1.38			1.41			2.60																											1.75			1.33	5	
	J20-J22			1.23			1.33											1.05	1.78									1.71							1.04	1.04		1.02	1.03	1.48	10	
	J30-J39																		1.33				1.03	1.04	1.26			1.38		1.03	1.29	1.03	1.03				1.26		1.01	1.13	12	
	J40-J47																	1.04										1.52			1.27						1.29		1.01	1.24	6	
	J60-J70																2.81																								1	
	J80-J86																					13.84																			1	
	J90-J94							1.39	1.43					1.25	1.22																										4	
	J95																															1.64	1.42								2	
	J96-J99																																								0	
	Age Total / Pollutant	1	1	3	0	0	5	1	1	3	0	0	1	2	1	1	2	3	4	0	1	5	2	2	3	1	2	9	1	3	8	3	4	3	2	3	10	2	5	14		Grand Total
	Age Total	5			5			5			1			4			9			6			7			12			12			10			15			21				112

$PM_{2.5}$ PM_{10} O_3

When separated out into sub-disease classifications, a total of 112 significant observations (RR>1.0) were seen in the Chiang Mai data: 17 associated with $PM_{2.5}$ (15.18%), 26 associated with PM_{10} (23.24%), and 69 associated with ozone (61.61%). The greatest number of significant observations were seen in the 60+ years age group (18.75%), followed by the 55-59 years age group (13.39%). The greatest number of significant observations were seen for the J00-J06 classification - acute upper respiratory infections (25.00%). When considering the relative risk values, the relationships between cancer (C81-C96) and ozone in the 5-9 age group (8.86), eye diseases (H15-H22) and ozone in the 30-34 age group (2.29), cardiovascular disease (I95-I99) and ozone (29.61) in the 30-34 age group, respiratory disease (J80-J86) and ozone in the 30-34 age group (13.84), cancer (C30-C39) and ozone in the 55-59 age group (2.32), and cardiovascular disease (I70-I79) and ozone in the 55-59 age group (4.58) stand out as being quite large and may require a closer assessment.

Saraburi

Table 12. Significant observations (RR>1.0) by age group in Saraburi.

Age	Cancer			Eye diseases			Cardiovascular diseases			Respiratory diseases			Total / Age group
Pollutant	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	
0 - 4											1.01		1
5 - 9													0
10 - 14	1.45	1.23									1.02		3
15 - 19	1.34	1.20						1.09			1.02		4
20 - 24											1.04		1
25 - 29										1.04	1.05		2
30 - 34										1.05	1.04		2
35 - 39									1.03	1.03	1.04		3
40 - 44								1.01	1.04		1.04		3
45 - 49		1.04	1.17					1.01	1.02		1.04		5
50 - 54		1.05						1.01	1.03		1.03		4
55 - 59	1.47	1.14	1.25					1.01	1.06	1.03	1.05		7
60+	1.12	1.06			1.03			1.01	1.04	1.01	1.04		7
Category Total / Pollutant	4	6	2	0	1	0	0	6	6	5	12	0	Grand Total
Category Total	12			1			12			17			42

$PM_{2.5}$ **PM_{10}** **O_3**

There was a total of 42 significant observations (RR>1.0) in the Saraburi data when ICD-10 data were grouped according to disease classification (cancer, eye diseases, cardiovascular diseases, and respiratory diseases): 9 associated with $PM_{2.5}$ (21.43%), 25 associated with PM_{10} (59.52%), and 8 associated with ozone (19.05%). The greatest number of significant observations were in the 55-59 years and 60+ years age groups (each 16.67%), followed by the 45-49 years age group (11.90%). The greatest number of significant observations were seen for respiratory effects (40.48%).

Table 13. Significant observations (RR>1.0) by ICD-10 in Saraburi.

Saraburi

	ICD-10 code	0 - 4			5 - 9			10 - 14			15 - 19			20 - 24			25 - 29			30 - 34			35 - 39			40 - 44			45 - 49			50 - 54			55 - 59			60+			Code Total	Category Total
Cancer	C30-C39																																	1.10		1.78	1.26	1.60	1.15	1.07		6	11
	C81-C96				1.16		1.32	1.48	1.24		1.36	1.20																														6	
Eye diseases	H10-H11																																									0	2
	H15-H22																																						1.16			1	
	H40-H42																																							1.04		1	
Cardiovascular Diseases	I10-I16											1.12						1.05									1.01			1.02			1.02			1.01			1.02		7	35
	I20-I25											1.63			t												1.05									1.02			1.02		4	
	I26-I28																																								0	
	I30-I52																								1.30					1.05		1.11	1.07		1.10	1.04			1.03		7	
	I60-69																	1.14		1.34						1.13	1.06		1.11	1.04		1.13	1.03	1.13				1.04	1.04		11	
	I70-I79																																								0	
	I80-I89											1.11		1.33		1.41							1.22	1.10	1.85																6	
	I95-I99																																								0	
Respiratory diseases	J00-J06		1.01						1.02			1.02			1.04		1.05	1.05		1.05	1.04		1.03	1.04			1.04			1.04			1.03		1.05	1.06		1.04	1.05		17	54
	J09-J18																					1.47																	1.07	1.31	3	
	J20-J22					1.04												1.08						1.09						1.15			1.07				1.49		1.07		7	
	J30-J39		1.02			1.03			1.04									1.06					1.16	1.08						1.05			1.04	1.14		1.06			1.04		11	
	J40-J47		1.02						1.04						1.10					1.10	1.04						1.04						1.02		1.06	1.04			1.03		10	
	J60-J70																																								0	
	J80-J86																																1.31								1	
	J90-J94																			1.62						2.06				1.21					1.21						4	
	J95																																								0	
	J96-J99																		3.69																						1	
	Age Total / Pollutant	0	3	0	1	2	1	1	4	0	1	5	0	1	2	1	1	5	1	4	2	1	3	4	2	2	5	0	1	7	0	2	9	2	5	7	2	4	11	1		Grand Total
	Age Total	3			4			5			6			4			7			7			9			7			8			13			14			16				103

$PM_{2.5}$ PM_{10} O_3

When separated out into sub-disease classifications, a total of 103 significant observations (RR>1.0) were seen in the Saraburi data: 26 associated with $PM_{2.5}$ (25.24%), 66 associated with PM_{10} (64.08%), and 11 associated with ozone (10.68%). The greatest number of significant observations were seen in the 60+ years age group (15.53%), followed by the 55-59 years age group (13.59%). The greatest number of significant observations were seen for the J00-J06 classification - acute upper respiratory infections (16.51%).

Songkhla

Table 14. Significant observations (RR>1.0) by age group in Songkhla.

Age	Cancer			Eye diseases			Cardiovascular diseases			Respiratory diseases			Total / Age group
	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	$PM_{2.5}$	PM_{10}	O_3	
0 - 4				1.14		1.07			1.22	1.04	1.01	1.02	6
5 - 9						1.10			1.26			1.06	3
10 - 14						1.14	1.26	1.11	1.24			1.09	5
15 - 19			1.19						1.20			1.13	3
20 - 24			1.36	1.14	1.06				1.16			1.10	5
25 - 29	1.21					1.09	1.16	1.08	1.26			1.09	6
30 - 34			1.17					1.02	1.22			1.07	4
35 - 39	1.23	1.10	1.18			1.12		1.03	1.23			1.08	7
40 - 44		1.04				1.06		1.04	1.24		1.02	1.12	6
45 - 49			1.11		1.02	1.07	1.02	1.04	1.22			1.11	7
50 - 54			1.12		1.03	1.07	1.06	1.05	1.22		1.01	1.11	8
55 - 59						1.09	1.06	1.06	1.22			1.10	5
60+			1.12	1.05	1.03	1.07	1.04	1.05	1.21			1.09	8
Category Total / Pollutant	**2**	**2**	**7**	**3**	**4**	**10**	**6**	**9**	**13**	**1**	**3**	**13**	**Grand Total**
Category Total	**11**			**17**			**28**			**17**			**73**

$PM_{2.5}$ PM_{10} O_3

There was a total of 73 significant observations (RR>1.0) in the Songkhla data when ICD-10 data were grouped according to disease classification (cancer, eye diseases, cardiovascular diseases, and respiratory diseases): 12 associated with $PM_{2.5}$ (16.44%), 18 associated with PM_{10} (24.66%), and 43 associated with ozone (58.90%). The greatest number of significant observations were in the 50-54 years and 60+ years groups (both 10.96%), followed by the 35-39 years age group (9.59%). The greatest number of significant observations were seen for cardiovascular effects (38.36%).

Table 15. Significant observations (RR>1.0) by ICD-10 in Songkhla.

Songkhla

	ICD-10 code	0 - 4			5 - 9			10 - 14			15 - 19			20 - 24			25 - 29			30 - 34			35 - 39			40 - 44			45 - 49			50 - 54			55 - 59			60+			Code Total	Category Total
Cancer	C30-C39																							1.10	1.16						1.17			1.09						1.07	5	
	C81-C96							1.22	1.11				1.18			1.36	1.31	1.11				1.19	1.33	1.10	1.15			1.10				1.16	1.07	1.11					1.05	1.12	16	
Eye diseases	H10-H11	1.13		1.07	1.14		1.12			1.12	1.16			1.18	1.07				1.09				1.09		1.13			1.09			1.06			1.07			1.08	1.06	1.04	1.07	18	
	H15-H22	1.35																																				1.16	1.08		3	
	H40-H42																1.33	1.11															1.04				1.06				4	
Cardiovascular Diseases	I10-I16																	1.05	1.08			1.08			1.11			1.11			1.08	1.04	1.02	1.08	1.04	1.02	1.08	1.04	1.02	1.06	15	
	I20-I25											1.25							1.52	1.32	1.11	1.22			1.22			1.12		1.05	1.24		1.05	1.20		1.06	1.21		1.05	1.21	15	
	I26-I28																																								0	
	I30-I52							1.34	1.12								1.37	1.13							1.10			1.09			1.07			1.07		1.03	1.09			1.09	11	
	I60-69												1.25						1.18	1.14					1.07			1.06			1.08			1.10			1.09			1.09	9	
	I70-I79																														1.21									1.06	2	
	I80-I89						1.20			1.24	1.19								1.09			1.08									1.15			1.16			1.07			1.09	9	
	I95-I99																																								0	
Respiratory diseases	J00-J06	1.04	1.02	1.03			1.06			1.10			1.13			1.09			1.09			1.07			1.09			1.13			1.13			1.12			1.13			1.10	15	
	J09-J18	1.13	1.04										1.28	1.24	1.13	1.21									1.19										1.19	1.11	1.18				10	
	J20-J22									1.09			1.17			1.12			1.18			1.19			1.11		1.04	1.14			1.12	1.11	1.05	1.09						1.11	13	
	J30-J39			1.15	1.14	1.05	1.05	1.07		1.08	1.12		1.10			1.08			1.09			1.05			1.06			1.09			1.13		1.04	1.09			1.08			1.06	18	
	J40-J47			1.02	1.10	1.04	1.08			1.07						1.12			1.09									1.09			1.08			1.12			1.06			1.09	12	
	J60-J70																																								0	
	J80-J86													1.79																											1	
	J90-J94	1.86	1.28																																						2	
	J95																																								0	
	J96-J99	1.15	1.08																																1.45						3	
	Age Total / Pollutant	6	4	4	3	2	5	3	2	6	3	1	6	3	2	6	3	4	9	2	1	7	2	2	11	0	1	10	0	1	12	3	6	12	3	4	11	3	5	13		0
	Age Total	14			10			11			10			11			16			10			15			11			13			21			18			21				181

PM2.5 PM10 O3

When separated out into sub-disease classifications, a total of 181 significant observations (RR>1.0) were seen in the Songkhla data: 34 associated with $PM_{2.5}$ (18.79%), 35 associated with PM_{10} (19.34%), and 112 associated with ozone (61.89%). The greatest number of significant observations were seen in the 50-54 years and 60+ years age group (each 11.60%), followed by the 55-59 years age group (9.95%). The greatest number of significant observations were seen for the H10-H11 – disorders of conjunctiva, and J30-J39 classification - other diseases of the upper respiratory tract (each 9.95%).

Comparing among the three provinces for ICD-10 data that were grouped according to disease classification (cancer, eye diseases, cardiovascular diseases, and respiratory diseases), Songkhla had the greatest number of significant observations (RR>1.0), followed by Chiang Mai and then Saraburi. When separated out into sub-disease classifications (ICD-10), Songkhla had the greatest number of significant observations, followed by Saraburi and then Chiang Mai. Chiang Mai and Saraburi provinces had the greatest number of significant observations associated with respiratory effects (J00-J06 - acute and upper respiratory effects), while Songkhla had the greatest number of significant observations associated with cardiovascular effects.

Significant Findings by Pollutant

Ozone

For ozone, for the 3 provinces and 23 disease classifications, 192 significant observations (RR greater than 1.0) were seen, as follows:

Chiang Mai had 69 significant observations, with 3 in the 0-4 age group, 5 in the 5-9 age group, 3 in the 10-14 age group, 1 in the 15-19 age group, 1 in the 20-24 age group, 4 in the 25-29 age group, 5 in the 30-34 age group, 3 in the 35-39 age group, 9 in the 40-44 age group, 8 in the 45-49 age group, 3 in the 50-54 age group, 10 in the 55-59 age group, and 14 in the 60+ age group. The greatest number of significant health observations (RR>1.00) across age groups was seen for J00-J06 - acute upper respiratory infections (26), J30-J39 - other diseases of the upper respiratory tract (20), J20-J22 - other acute lower respiratory infections (16), I10-I16 - hypertensive diseases (15), I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified and J40-J47 - chronic lower respiratory diseases (14 each), I20-I25 - ischemic heart diseases (12), and H10-H11 - disorders of conjunctiva , I30-I52 - other forms of heart disease , and J09-J18 - influenza and pneumonia (11 each).

Saraburi had 11 significant observations, with 0 in the 0-4 age group, 1 in the 5-9 age group, 0 in the 10-14 age group, 0 in the 15-19 age group, 1 in the 20-24 age group, 1 in the 25-29 age group, 1 in the 30-34 age group, 2 in the 35-39 age group, 0 in the 40-44 age group, 0 in the 45-49 age group, 2 in the 50-54 age group, 2 in the 55-59 age group, and 1 in the 60+ age group. The greatest number of significant health observations (RR>1.00) across age groups was seen for I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified and J09-J18 - influenza and pneumonia (2 each), and C30-C39 - malignant neoplasms of respiratory and intrathoracic organs, C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue, I30-52 - other forms of heart disease, I60-I69 - cerebrovascular diseases, J20-J22 - other acute lower respiratory infections, J30-J39 - other diseases of the upper respiratory tract, and J96-J99 - other diseases of the respiratory system (1 each).

Songkhla had 112 significant observations, with 4 in the 0-4 age group, 5 in the 5-9 age group, 6 in the 10-14 age group, 6 in the 15-19 age group, 6 in the 20-24 age group, 9 in the 25-29 age group, 7 in the 30-34 age group, 11 in the 35-39 age group, 10 in the 40-44 age group, 12 in the 45-49 age group, 12 in the 50-54 age group, 11 in the 55-59 age group and 13 in the 60-120 age group. The greatest number of significant health observations (RR>1.00) across age groups were seen for J00-J06 - acute upper respiratory infections and J30-J39 - other diseases of the upper respiratory tract (13 each), H10-H11 - disorders of conjunctiva, J20-J22 - other acute lower respiratory infections, and J40-J47 - chronic lower respiratory diseases (10 each), I10-I16 - hypertensive diseases, I20-I25 - ischemic heart diseases, I60-I69 - cerebrovascular diseases, and I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified (8 each), C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue (7), I30-I52 - other forms of heart disease (6), and C30-C39 - malignant neoplasms of respiratory and intrathoracic organs and J09-J18 - influenza and pneumonia (4 each).

Overall, for all three provinces, there were 192 significant observations (RR>1.0), with the disease classification with highest significant observations in association with ozone levels being J00-J06 - acute upper respiratory infections (26), J30-J39 - other diseases of the upper respiratory tract (20), J20-J22 - other acute lower respiratory infections (16), I10-I16 - hypertensive diseases and I60-I69 - cerebrovascular diseases (15 each), I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified and J40-J47 - chronic lower respiratory diseases (14 each), I20-I25 - ischemic heart diseases (12), H10-H11 - disorders of conjunctiva, I30-I52 - other forms of heart disease, and J09-J18 - influenza and pneumonia (11 each), C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue (10), and C30-C39 - malignant neoplasms of respiratory and intrathoracic organs (7).

$PM_{2.5}$

For $PM_{2.5}$, for the 3 provinces and 13 disease classifications, 77 significant observations (RR greater than 1.00) were seen, as follows:

Chiang Mai had 17 significant observations, with 1 in the 0-4 age group, 0 in the 5-9 age group, 1 in the 10-14 age group, 0 in the 15-19 age group, 2 in the 20-24 age group, 2 in the 25-29 age group, 0 in the 30-34 age group, 2 in the 35-39 age group, 1 in the 40-44 age group, 1 in the 45-49 age group, 3 in the 50-54 age group, 2 in the 55-59 age group, and 2 in the 60+ age group. The greatest number of significant health observations (RR>1.00) across age groups was seen for J00-J06 - acute upper respiratory infections (7), J20-J22 - other acute lower respiratory infections, J30-J39 - other diseases of the upper respiratory tract, and J90-J94 - other diseases of the pleura (2 each), and C81-96 - malignant neoplasms of lymphoid, hematopoietic and related tissue, H10-H11 - disorders of conjunctiva, J60-J70 - lung diseases due to external agents, and J95 - intraoperative and postprocedural complications and disorders of respiratory system, not elsewhere classified (1 each).

Saraburi had 26 significant observations, with 0 in the 0-4 age group, 1 in the 5-9 age group, 1 in the 10-14 age group, 1 in the 15-19 age group, 1 in the 20-24 age group, 1 in the 25-29 age group, 4 in the 30-34 age group, 3 in the 35-39 age group, 2 in the 40-44 age group, 1 in the 45-49 age group, 2 in the 50-54 age group, 5 in the 55-59 age group, and 4 in the 60+ age group. The greatest number of significant health observations (RR>1.00) across age groups was seen for I60-I69 - cerebrovascular diseases and J00-J06 - acute upper respiratory infections (5 each), C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue and J90-J94 - other diseases of the pleura (3 each), C30-C39 - malignant neoplasms of respiratory and intrathoracic organs, I30-I52 - other forms of heart disease, I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified and J40-J47 - chronic lower respiratory diseases (2 each), and H15-H22 - disorders of sclera, cornea, iris and ciliary body and J30-J39 - other diseases of the upper respiratory tract (1 each).

Songkhla had 34 significant observations, with 6 in the 0-4 age group, 3 in the 5-9 age group, 3 in the 10-14 age group, 3 in the 15-19 age group, 3 in the 20-24 age group, 3 in the 25-29 age group, 2 in the 30-34 age group, 2 in the 35-39 age group, 0 in the 40-44 age group, 0 in the 45-49 age group, 3 in the 50-54 age group, 3 in the 55-59 age group and 3 in the 60-120 age group. The greatest number of significant health observations (RR>1.00) across age groups was seen for H10-H11 - disorders of conjunctiva (6), C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue and (4), I10-I16 - hypertensive diseases, J09-J18 - influenza and pneumonia, and J30-J39 - other diseases of the upper respiratory tract (3 each), H15-H22 - disorders of sclera, cornea, iris and ciliary body, I30-I52 - other forms of heart disease, and J96-J99 - other diseases of the respiratory system (2 each), and H40-H42 - glaucoma, I20-I25 - ischemic heart diseases, I60-I69 - cerebrovascular diseases, I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified, J00-J06 - acute upper respiratory infections, J20-J22 - other acute lower respiratory infections, J40-J47 - chronic lower respiratory diseases, J80-J86 - other respiratory diseases principally affecting the interstitium and suppurative and necrotic conditions of the lower respiratory tract, and J90-J94 - other diseases of the pleura (1 each).

Overall, for all three provinces, the disease classification with highest significant observations in association with $PM_{2.5}$ levels were J00-J06 - acute upper respiratory infections (13), C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue (8), H10-H11 - disorders of conjunctiva (7), I60-I69 - cerebrovascular diseases, J30-J39 - other diseases of the upper respiratory tract, and J90-J94 - other diseases of the pleura (6 each), I30-I52 - other forms of heart disease (4), and H15-H22 - disorders of sclera, cornea, iris and ciliary body, I10-I16 - hypertensive diseases, I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified, J9-J18 - influenza and pneumonia, J20-J22 - other acute lower respiratory infections, and J40-J47 - chronic lower respiratory diseases (3 each).

PM_{10}

For PM_{10}, for the 3 provinces and 13 disease classifications, 127 significant observations (RR greater than 1.00) were seen, as follows:

Chiang Mai had 26 significant observations, with 1 in the 0-4 age group, 0 in the 5-9 age group, 1 in the 10-14 age group, 0 in the 15-19 age group, 1 in the 20-24 age group, 3 in the 25-29 age group, 1 in the 30-34 age group, 2 in the 35-39 age group, 2 in the 40-44 age group, 3 in the 45-49 age group, 4 in the 50-54 age group, 3 in the 55-59 age group, and 5 in the 60+ age group. The greatest number of significant health observations (RR>1.00) across age groups was seen for J00-J06 - acute upper respiratory infections (8), I10-I16 - hypertensive diseases and J30-J39 - other diseases of the upper respiratory tract (4 each), J20-J22 - other acute lower respiratory infections (3), J40-J47 - chronic lower respiratory diseases and J90-J94 - other diseases of the pleura (2 each), and H10-H11 - disorders of conjunctiva, I20-I25 – ischemic heart diseases, and J95 - intraoperative and postprocedural complications and disorders of respiratory system, not elsewhere classified (1 each).

Saraburi had 66 significant observations, with 3 in the 0-4 age group, 2 in the 5-9 age group, 4 in the 10-14 age group, 5 in the 15-19 age group, 2 in the 20-24 age group, 5 in the 25-29 age group, 2 in the 30-34 age group, 4 in the 35-39 age group, 5 in the 40-44 age group, 7 in the 45-49 age group, 9 in the 50-54 age group, 7 in the 55-59 age group, and 11 in the 60+ age group. The greatest number of significant health observations (RR>1.00) across age groups was seen for J00-J06 - acute upper respiratory infections (12), J30-J39 - other diseases of the upper respiratory tract (9), J40-J47 - chronic lower respiratory diseases (8), I10-I16 - hypertensive diseases (7), J20-J22 - other acute lower respiratory infections (6), I60-I69 - cerebrovascular diseases (5), I20-I25 - ischemic heart diseases and I30-I52 - other forms of heart disease (4 each), C30-C39 - malignant neoplasms of respiratory and intrathoracic organs (3), and C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue and I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified (2 each).

Songkhla had 35 significant observations, with 4 in the 0-4 age group, 2 in the 5-9 age group, 2 in the 10-14 age group, 1 in the 15-19 age group, 2 in the 20-24 age group, 4 in the 25-29 age group, 1 in the 30-34 age group, 2 in the 35-39 age group, 1 in the 40-44 age group, 1 in the 45-49 age group, 6 in the 50-54 age group, 4 in the 55-59 age group and 5 in the 60+ age group. The greatest number of significant health observations (RR>1.00) across age groups was seen for I20-I25 - ischemic heart diseases (6), C81-96 - malignant neoplasms of lymphoid, hematopoietic and related tissue (5), I10-I16 - hypertensive diseases (4), I30-I52 - other forms of heart disease and J09-J18 - influenza and pneumonia (3 each), and H10-H11 - disorders of conjunctiva, H40-H42 - glaucoma, J20-J22 - other acute lower respiratory infections, and J30-J39 - other diseases of the upper respiratory tract (2 each).

Overall, for all three provinces, the disease classification with highest significant observations in association with PM_{10} levels were J00-J06 - acute upper respiratory infections (21), I10-I16 - hypertensive diseases and J30-J39 - other diseases of the upper respiratory tract (15 each), I20-I25 - ischemic heart diseases, J20-J22 - other acute lower respiratory infections, and J40-J47 - chronic lower respiratory diseases (11 each), C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue and I30-I52 - other forms of heart disease (7 each), I60-I69 - cerebrovascular diseases (5), C30-C39 - malignant neoplasms of respiratory and intrathoracic organs, J09-J18 - influenza and pneumonia, and J90-J94 - other diseases of the pleura (4 each), and H10-H11- disorders of conjunctiva and H40-H42 - glaucoma (3 each).

Disability-Adjusted Life Years (DALYs)

Disability-adjusted life years were calculated for each of the 23 ICD-10 classifications and summed up for each of the 3 provinces. Since each ICD-10 represents a range of diseases/health effects with varying severity, and since the health data does not specify exactly what disease/effect each individual patient is afflicted with, it is not possible to assign an exact DALY. The approach used in this study is to determine the range from least to most severe disease/health effect within each ICD-10 classification, and to then calculate a range for the respective DALY for that classification, and then multiply that with the incidence of the disease/effect classification. The DALYs are then summed up for the province and then presented as DALYs per 1,000 and per 100,000 of the population (see Table 16).

The greatest number of DALYs, i.e. the greatest negative impacts on health, were seen in Songkhla (150.6-264.2 years per 1,000 population or 15,056-26,415 years per 100,000 population. Saraburi was next with 78.0-317.1 years per 1,000 population or 7,800-31,706 year per 100,000 population, while Chiang Mai had a range of DALYs from 32.8-176.1 years per 1,000 population or 3,283-17,612 years per 100,000 population. It should be pointed out that while Songkhla had the highest lower bound value of the DALYs at 150.6 years, the highest upper bound value was for Saraburi at 317.1 years. Importantly, these DALYs were calculated as a sum total for all 3 pollutants, so they represent the total effects on health, potentially, from exposure to all 3 air pollutants.

Table 16. Disability-adjusted life years (total for all ICD-10 classifications).

ICD-10	Chiang Mai		Saraburi		Songkhla	
	Lower	Upper	Lower	Upper	Lower	Upper
C30-C39	110.336	710.494	103.536	223.994	2613.720	4050.155
C81-C96	180.644	449.276	11.880	187.770	5422.748	7151.267
H10-H11	315.306	315.306	90.018	90.018	446.364	446.364
H15-H22	57.834	57.834	13.986	13.986	123.120	123.120
H40-H42	189.007	1121.848	22.847	135.608	154.721	918.344
I10-I16	1636.570	7028.230	382.830	1670.370	1558.759	5270.821
I20-I25	316.406	2822.924	226.576	973.504	2798.087	6284.948
I26-I28	7.392	96.768	1.287	16.848	251.775	600.900
I30-I52	2528.757	6370.728	1280.363	2122.652	23050.899	26762.796
I60-69	394.108	4622.916	43.770	1198.840	8157.116	16045.732
I70-I79	5.301	164.052	7.326	38.052	181.848	860.096
I80-I89	68.267	2112.684	8.512	263.424	204.861	3003.772
I95-I99	5.605	173.460	0.418	12.936	2.755	85.260
J00-J06	181.122	6610.953	61.194	2233.581	167.126	5794.799
J09-J18	242.644	982.606	320.112	501.588	5453.888	6720.812
J20-J22	35.478	1294.947	7.884	287.766	52.578	1919.097
J30-J39	56.502	2062.323	15.048	549.252	90.804	2441.046
J40-J47	104.496	2791.704	21.594	788.181	1240.170	5041.155
J60-J70	0.264	9.636	81.458	90.617	190.188	232.362
J80-J86	17.218	39.157	98.178	111.597	304.120	372.280
J90-J94	2.898	105.777	0.294	10.731	241.036	412.714
J95	0.150	5.475	0.150	5.475	3.302	28.223
J96-J99	1247.872	1378.228	53.026	68.149	3003.398	3180.827
Total	**7704.177**	**41327.326**	**2852.287**	**11594.939**	**55713.383**	**97746.890**
per 1,000	**32.833**	**176.124**	**77.995**	**317.061**	**150.561**	**264.154**
per 100,000	**3283.277**	**17612.402**	**7799.527**	**31706.150**	**15056.125**	**26415.365**

Finally, an estimate of the total population likely affected by exposure to the 3 air pollutants of interest was calculated for each of the 3 provinces for each year from 2012 to 2016, and these are presented in Figures 25 to 39. These numbers are equivalent to the total population expected to be affected by exposure to the pollutants of interest at levels above the national standards, although the severity of the resultant effect can't be specified as each ICD-10 category is a range of diseases. Note that no estimates were calculated for the ozone data, as the ozone levels were not higher than the national standards. These estimates can then be used to calculate the potential economic impacts associated with these air pollutant exposures.

Table 17. Estimate of size of impacted population (Chiang Mai 2012).

	ICD-10 code	$PM_{2.5}$		PM_{10}		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	-	-	-	-
	C81-C96	-	-	-	-	-	-
Eye diseases	H10-H11	1295	1295	-	-	-	-
	H15-H22	-	-	-	-	-	-
	H40-H42	-	-	-	-	-	-
Cardiovascular Diseases	I10-I16	-	-	307	1339	-	-
	I20-I25	-	-	-	-	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	-	-	-	-	-	-
	I60-69	-	-	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	-	-	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	26	3596	88	6159	-	-
	J09-J18	-	-	-	-	-	-
	J20-J22	51	3596	129	7547	-	-
	J30-J39	75	2734	129	4714	-	-
	J40-J47	-	-	45	6159	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	-	-	-	-
	J90-J94	476	23076	671	35371	-	-
	J95	845	30826	948	34617	-	-
	J96-J99	-	-	-	-	-	-

Table 18. Estimate of size of impacted population (Chiang Mai 2013).

	ICD-10 code	$PM_{2.5}$		PM_{10}		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	-	-	-	-
	C81-C96	-	-	-	-	-	-
Eye diseases	H10-H11	1710	1710	-	-	-	-
	H15-H22	-	-	-	-	-	-
	H40-H42	-	-	-	-	-	-
Cardiovascular Diseases	I10-I16	-	-	54	234	-	-
	I20-I25	-	-	-	-	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	-	-	-	-	-	-
	I60-69	-	-	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	-	-	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	34	4777	15	1069	-	-
	J09-J18	-	-	-	-	-	-
	J20-J22	68	4777	22	1307	-	-
	J30-J39	100	3643	22	819	-	-
	J40-J47	-	-	8	1069	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	-	-	-	-
	J90-J94	600	28342	113	5834	-	-
	J95	997	36404	157	5720	-	-
	J96-J99	-	-	-	-	-	-

Table 19. Estimate of size of impacted population (Chiang Mai 2014).

	ICD-10 code	$PM_{2.5}$		PM_{10}		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	-	-	-	-
	C81-C96	-	-	-	-	-	-
Eye diseases	H10-H11	1594	1594	-	-	-	-
	H15-H22	-	-	-	-	-	-
	H40-H42	-	-	-	-	-	-
Cardiovascular Diseases	I10-I16	-	-	344	1501	-	-
	I20-I25	-	-	-	-	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	-	-	-	-	-	-
	I60-69	-	-	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	-	-	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	32	4447	98	6868	-	-
	J09-J18	-	-	-	-	-	-
	J20-J22	63	4447	144	8400	-	-
	J30-J39	93	3388	144	5266	-	-
	J40-J47	-	-	50	6868	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	-	-	-	-
	J90-J94	567	26961	728	37526	-	-
	J95	959	35002	1008	36790	-	-
	J96-J99	-	-	-	-	-	-

Table 20. Estimate of size of impacted population (Chiang Mai 2015).

	ICD-10 code	$PM_{2.5}$		PM_{10}		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	-	-	-	-
	C81-C96	-	-	-	-	-	-
Eye diseases	H10-H11	1570	1570	-	-	-	-
	H15-H22	-	-	-	-	-	-
	H40-H42	-	-	-	-	-	-
Cardiovascular Diseases	I10-I16	-	-	368	1608	-	-
	I20-I25	-	-	-	-	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	-	-	-	-	-	-
	I60-69	-	-	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	-	-	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	31	4378	105	7327	-	-
	J09-J18	-	-	-	-	-	-
	J20-J22	62	4378	154	8951	-	-
	J30-J39	91	3336	154	5625	-	-
	J40-J47	-	-	54	7327	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	-	-	-	-
	J90-J94	560	26668	763	38782	-	-
	J95	951	34698	1043	38063	-	-
	J96-J99	-	-	-	-	-	-

Table 21. Estimate of size of impacted population (Chiang Mai 2016).

	ICD-10 code	$PM_{2.5}$		PM_{10}		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	-	-	-	-
	C81-C96	-	-	-	-	-	-
Eye diseases	H10-H11	1523	1523	-	-	-	-
	H15-H22	-	-	-	-	-	-
	H40-H42	-	-	-	-	-	-
Cardiovascular Diseases	I10-I16	-	-	395	1723	-	-
	I20-I25	-	-	-	-	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	-	-	-	-	-	-
	I60-69	-	-	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	-	-	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	30	4243	113	7823	-	-
	J09-J18	-	-	-	-	-	-
	J20-J22	60	4243	165	9544	-	-
	J30-J39	89	3232	165	6014	-	-
	J40-J47	-	-	58	7823	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	-	-	-	-
	J90-J94	546	26078	799	40024	-	-
	J95	934	34081	1077	39326	-	-
	J96-J99	-	-	-	-	-	-

Table 22. Estimate of size of impacted population (Saraburi 2012).

	ICD-10 code	$PM_{2.5}$		PM_{10}		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	375	15755	632	18560	-	-
	C81-C96	491	9745	1071	18190	-	-
Eye diseases	H10-H11	-	-	-	-	-	-
	H15-H22	624	624	-	-	-	-
	H40-H42	-	-	358	2125	-	-
Cardiovascular Diseases	I10-I16	-	-	138	4357	-	-
	I20-I25	88	5892	210	15630	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	142	3704	300	7587	-	-
	I60-69	66	11334	173	15439	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	277	11138	418	13661	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	26	941	20	3451	-	-
	J09-J18	-	-	105	3846	-	-
	J20-J22	-	-	69	5932	-	-
	J30-J39	69	2532	38	4204	-	-
	J40-J47	-	-	38	4528	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	203	7411	-	-
	J90-J94	85	3092	185	6735	-	-
	J95	-	-	-	-	-	-
	J96-J99	-	-	-	-	-	-

Table 23. Estimate of size of impacted population (Saraburi 2013).

	ICD-10 code	$PM_{2.5}$		PM_{10}		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	399	16266	593	18090	-	-
	C81-C96	520	10261	1033	17682	-	-
Eye diseases	H10-H11	-	-	-	-	-	-
	H15-H22	662	662	-	-	-	-
	H40-H42	-	-	332	1972	-	-
Cardiovascular Diseases	I10-I16	-	-	126	4140	-	-
	I20-I25	94	6235	194	15560	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	152	3946	278	7111	-	-
	I60-69	71	11893	160	14742	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	293	11693	395	12950	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	28	1007	18	3224	-	-
	J09-J18	-	-	99	3605	-	-
	J20-J22	-	-	64	5677	-	-
	J30-J39	74	2687	35	3952	-	-
	J40-J47	-	-	35	4269	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	199	7263	-	-
	J90-J94	90	3270	179	6517	-	-
	J95	-	-	-	-	-	-
	J96-J99	-	-	-	-	-	-

Table 24. Estimate of size of impacted population (Saraburi 2014).

	ICD-10 code	$PM_{2.5}$ Lower	$PM_{2.5}$ Upper	PM_{10} Lower	PM_{10} Upper	O_3 Lower	O_3 Upper
Cancer	C30-C39	422	16738	577	17884	-	-
	C81-C96	548	10767	1017	17462	-	-
Eye diseases	H10-H11	-	-	-	-	-	-
	H15-H22	701	701	-	-	-	-
	H40-H42	-	-	322	1912	-	-
Cardiovascular Diseases	I10-I16	-	-	122	4052	-	-
	I20-I25	101	6576	187	15525	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	162	4190	269	6921	-	-
	I60-69	76	12437	155	14454	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	309	12235	386	12661	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	29	1075	18	3134	-	-
	J09-J18	-	-	96	3509	-	-
	J20-J22	-	-	62	5571	-	-
	J30-J39	78	2842	34	3851	-	-
	J40-J47	-	-	34	4165	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	197	7197	-	-
	J90-J94	94	3447	176	6425	-	-
	J95	-	-	-	-	-	-
	J96-J99	-	-	-	-	-	-

Table 25. Estimate of size of impacted population (Saraburi 2015).

	ICD-10 code	$PM_{2.5}$ Lower	$PM_{2.5}$ Upper	PM_{10} Lower	PM_{10} Upper	O_3 Lower	O_3 Upper
Cancer	C30-C39	496	17964	586	18009	-	-
	C81-C96	634	12260	1026	17596	-	-
Eye diseases	H10-H11	-	-	-	-	-	-
	H15-H22	818	818	-	-	-	-
	H40-H42	-	-	328	1948	-	-
Cardiovascular Diseases	I10-I16	-	-	125	4105	-	-
	I20-I25	122	7611	191	15547	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	195	4955	274	7035	-	-
	I60-69	92	14011	158	14628	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	356	13807	392	12836	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	35	1293	18	3188	-	-
	J09-J18	-	-	98	3567	-	-
	J20-J22	-	-	64	5635	-	-
	J30-J39	91	3319	35	3912	-	-
	J40-J47	-	-	35	4228	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	198	7238	-	-
	J90-J94	109	3981	178	6481	-	-
	J95	-	-	-	-	-	-
	J96-J99	-	-	-	-	-	-

Table 26. Estimate of size of impacted population (Saraburi 2016).

	ICD-10 code	PM2.5		PM10		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	364	15507	579	17911	-	-
	C81-C96	478	9506	1019	17490	-	-
Eye diseases	H10-H11	-	-	-	-	-	-
	H15-H22	607	607	-	-	-	-
	H40-H42	-	-	323	1919	-	-
Cardiovascular Diseases	I10-I16	-	-	122	4063	-	-
	I20-I25	85	5734	188	15530	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	137	3594	270	6945	-	-
	I60-69	64	11073	155	14491	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	270	10878	387	12698	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	25	911	18	3146	-	-
	J09-J18	-	-	96	3521	-	-
	J20-J22	-	-	63	5585	-	-
	J30-J39	67	2461	34	3864	-	-
	J40-J47	-	-	34	4178	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	-	-	197	7206	-	-
	J90-J94	82	3010	176	6437	-	-
	J95	-	-	-	-	-	-
	J96-J99	-	-	-	-	-	-

Table 27. Estimate of size of impacted population (Songkhla 2012).

	ICD-10 code	PM2.5		PM10		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	2689	42503	-	-
	C81-C96	1667	34534	1452	46063	-	-
Eye diseases	H10-H11	1022	2768	1771	2956	-	-
	H15-H22	2501	4734	3326	3326	-	-
	H40-H42	2599	15426	1016	14895	-	-
Cardiovascular Diseases	I10-I16	527	2300	694	7221	-	-
	I20-I25	2702	35375	1331	65565	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	2830	39475	825	40138	-	-
	I60-69	783	24226	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	1020	31561	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	77	2813	102	3709	-	-
	J09-J18	231	14277	242	20348	-	-
	J20-J22	199	7272	242	8834	-	-
	J30-J39	131	9023	197	8834	-	-
	J40-J47	183	6668	197	7181	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	906	33076	-	-	-	-
	J90-J94	951	34705	982	35846	-	-
	J95	-	-	-	-	-	-
	J96-J99	263	23053	328	11986	-	-

Table 28. Estimate of size of impacted population (Songkhla 2013).

	ICD-10 code	$PM_{2.5}$		PM_{10}		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	3141	49649	-	-
	C81-C96	1883	38888	1713	53706	-	-
Eye diseases	H10-H11	1161	3123	2093	3473	-	-
	H15-H22	2825	5299	3900	3900	-	-
	H40-H42	2912	17285	1202	17367	-	-
Cardiovascular Diseases	I10-I16	599	2615	824	8519	-	-
	I20-I25	3029	39653	1571	74686	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	3170	44156	977	46627	-	-
	I60-69	885	27392	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	1150	35593	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	88	3199	121	4404	-	-
	J09-J18	262	16062	286	23637	-	-
	J20-J22	226	8235	286	10423	-	-
	J30-J39	149	10202	233	10423	-	-
	J40-J47	207	7556	233	8490	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	999	36468	-	-	-	-
	J90-J94	1046	38189	1114	40656	-	-
	J95	-	-	-	-	-	-
	J96-J99	297	25705	386	14084	-	-

Table 29. Estimate of size of impacted population (Songkhla 2014).

	ICD-10 code	$PM_{2.5}$		PM_{10}		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	3649	57676	-	-
	C81-C96	1786	36932	2013	62253	-	-
Eye diseases	H10-H11	1098	2964	2466	4062	-	-
	H15-H22	2679	5046	4551	4551	-	-
	H40-H42	2772	16452	1416	20131	-	-
Cardiovascular Diseases	I10-I16	566	2472	976	10011	-	-
	I20-I25	2883	37736	1846	84302	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	3018	42061	1154	53818	-	-
	I60-69	839	25966	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	1092	33780	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	83	3025	143	5215	-	-
	J09-J18	248	15260	336	27283	-	-
	J20-J22	214	7801	336	12249	-	-
	J30-J39	141	9671	274	12249	-	-
	J40-J47	196	7155	274	10002	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	958	34964	-	-	-	-
	J90-J94	1004	36647	1251	45669	-	-
	J95	-	-	-	-	-	-
	J96-J99	281	24521	451	16473	-	-

Table 30. Estimate of size of impacted population (Songkhla 2015).

	ICD-10 code	PM2.5		PM10		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	3650	57691	-	-
	C81-C96	1463	30391	2014	62268	-	-
Eye diseases	H10-H11	892	2432	2467	4063	-	-
	H15-H22	2195	4189	4553	4553	-	-
	H40-H42	2298	13640	1416	20136	-	-
Cardiovascular Diseases	I10-I16	459	2006	977	10014	-	-
	I20-I25	2388	31265	1846	84319	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	2503	34959	1154	53831	-	-
	I60-69	686	21240	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	896	27736	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	67	2454	143	5216	-	-
	J09-J18	203	12575	336	27289	-	-
	J20-J22	174	6366	336	12252	-	-
	J30-J39	115	7911	274	12252	-	-
	J40-J47	160	5834	274	10005	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	814	29696	-	-	-	-
	J90-J94	855	31216	1251	45677	-	-
	J95	-	-	-	-	-	-
	J96-J99	230	20477	451	16477	-	-

Table 31. Estimate of size of impacted population (Songkhla 2016).

	ICD-10 code	PM2.5		PM10		O_3	
		Lower	Upper	Lower	Upper	Lower	Upper
Cancer	C30-C39	-	-	3515	55549	-	-
	C81-C96	1641	34008	1933	59992	-	-
Eye diseases	H10-H11	1005	2725	2366	3905	-	-
	H15-H22	2462	4665	4378	4378	-	-
	H40-H42	2561	15201	1358	19400	-	-
Cardiovascular Diseases	I10-I16	518	2262	935	9612	-	-
	I20-I25	2663	34855	1772	81818	-	-
	I26-I28	-	-	-	-	-	-
	I30-I52	2789	38905	1107	51923	-	-
	I60-69	771	23846	-	-	-	-
	I70-I79	-	-	-	-	-	-
	I80-I89	1004	31075	-	-	-	-
	I95-I99	-	-	-	-	-	-
Respiratory diseases	J00-J06	76	2767	137	4997	-	-
	J09-J18	228	14061	322	26322	-	-
	J20-J22	196	7156	322	11760	-	-
	J30-J39	129	8881	263	11760	-	-
	J40-J47	180	6562	263	9597	-	-
	J60-J70	-	-	-	-	-	-
	J80-J86	895	32655	-	-	-	-
	J90-J94	939	34272	1216	44380	-	-
	J95	-	-	-	-	-	-
	J96-J99	259	22729	434	15836	-	-

Tables 32 to 34 show the results from the BenMAP (i.e. economic impacts) analysis. The numbers represent the economic valuation (in Thai Baht) of the benefits from reduction of air pollutant exposures to WHO Interim Targets 1, 2 and 3, or down to the WHO Guideline level (in 2017).

Table 32. Economic valuation of health benefits from reduction in air pollutant exposures (Chiang Mai, Thai Baht).

Reduction level	WHO Interim Target 1	WHO Interim Target 2	WHO Interim Target 3	WHO-guideline
PM_{10}	190,951,696	267,795,216	272,278,080	287,460,320
$PM_{2.5}$	1,671,776,000	1,827,832,064	1,858,622,080	1,891,682,816
Total	1,862,727,696	2,095,627,280	2,130,900,160	2,179,143,136

From the data summarized in Table 32, it can be seen that if the air concentrations of PM_{10} and $PM_{2.5}$ in Chiang Mai could be reduced the WHO Interim Target 1, the economic valuation of the total health benefits for that province would amount to 1.86 billion Thai Baht in 2017. Reduction of air concentrations of the two pollutants to WHO Interim Target 2 would have a total health benefit amounting to 2.09 billion Thai baht, and reduction to WHO Interim Target 3 would have a total health benefit amounting to 2.13 billion Thai baht for that province. If the air concentrations of the two pollutants were below the WHO guidelines, the total economic health benefits for Chiang Mai are estimated at 2.18 billion Thai baht.

Table 33. Economic valuation of health benefits from reduction in air pollutant exposures (Saraburi, Thai Baht).

Reduction level	WHO Interim Target 1	WHO Interim Target 2	WHO Interim Target 3	WHO-guideline
PM_{10}	730,345,600	769,043,520	737,510,528	767,780,288
$PM_{2.5}$	1,812,877,056	1,857,474,688	1,964,054,912	1,964,054,912
Total	2,543,222,656	2,626,518,208	2,701,565,440	2,731,835,200

From the data summarized in Table 33, it can be seen that if the air concentrations of PM_{10} and $PM_{2.5}$ in Saraburi could be reduced to WHO Interim Target 1, the economic valuation of the total health benefits for that province would amount to 2.54 billion Thai Baht in 2017. Reduction of air concentrations of the two pollutants to WHO Interim Target 2 would have a total health benefit amounting to 2.63 billion Thai baht, and a reduction to WHO Interim Target 3 would have a total health benefit amounting to 2.70 billion Thai baht for that province. If the air concentrations of the two pollutants were below the WHO guidelines, the total economic health benefits for Saraburi are estimated at 2.73 billion Thai baht.

Table 34. Economic valuation of health benefits from reduction in air pollutant exposures (Songkhla, Thai Baht).

Reduction level	WHO Interim Target 1	WHO Interim Target 2	WHO Interim Target 3	WHO-guideline
PM_{10}	273,250,112	197,962,192	235,873,664	235,873,664
$PM_{2.5}$	1,202,378,624	924,495,808	1,068,310,848	1,068,310,848
Total	1,475,628,736	1,122,458,000	1,304,184,512	1,304,184,512

From the data summarized in Table 34, it can be seen that if the air concentrations of PM_{10} and $PM_{2.5}$ in Songkhla could be reduced to WHO Interim Target 1, the economic valuation of the total health benefits for that province would amount to 1.48 billion Thai Baht in 2017. Reduction of air concentrations of the two pollutants to WHO Interim Target 2 would have a total health benefit amounting to 1.12 billion Thai baht, and a reduction to WHO Interim Target 3 would have a total health benefit amounting to 1.30 billion Thai baht for that province. If the air concentrations of the two pollutants were below the WHO guidelines, the total economic health benefits for Songkhla are estimated at 1.30 billion Thai baht.

DISCUSSION

In terms of the air quality in the vicinity of the 9 hospitals, 49.5% were in areas with concentrations of $PM_{2.5}$ ranging from 12.1 to 35.4 μg/m^3, followed by 22.1% in areas with up to but not exceeding 12.0 μg/m^3. For PM_{10}, 69.1% of the hospitals were situated in areas with concentrations ranging up to but not exceeding 54 μg/m^3, and 28.5% in areas ranging in PM_{10} concentrations between 55 and 154 μg/m^3. As for ozone, 98.9% of the hospitals were situated in areas with concentrations less than 0.054 PPM.

Table 35. Number of days where Thai National Ambient Air Quality Standards were exceeded.

Province	24-hour median			1-hour raw
	$PM_{2.5}$ (50 μg/m^3)	**PM_{10} (120 μg/m^3)**	**O_3 (70 ppb)**	**O_3 (100 ppb)**
Chiang Mai	332	91	0	58
Songkhla	8	7	5	10
Saraburi	353	509	0	250

For reference, the Thai national air quality standards are 120 μg/m^3 (PM_{10}, 24-hr), 50 μg/m^3 (PM_{10}, annual), 50 μg/m^3 ($PM_{2.5}$, 24-hr), 25 μg/m^3 ($PM_{2.5}$, annual) and 0.07 PPM (ozone, 8-hr). The number of days for which national $PM_{2.5}$ standards were exceeded was highest in Saraburi (353), followed closely by Chiang Mai (332), and lowest in Songkhla (8). For PM_{10}, the number of days for which national standards were exceeded was highest in Saraburi (509), followed by Chiang Mai (91), and lowest in Songkhla (7). For ozone, the number of days for which national standards were exceeded was highest in Songkhla (5), and national standards were not exceeded in Chiang Mai and Saraburi.

Table 36. Number of days where WHO Air Quality Guidelines were exceeded.

Province	24-hour median		
	$PM_{2.5}$ (25 μg/m^3)	**PM_{10} (50 μg/m^3)**	**O_3 (50 ppb)**
Chiang Mai	857	558	6
Songkhla	232	258	74
Saraburi	1083	1614	8

Note: WHO do not have a 1-hour O_3 guideline value. The 50 ppb O_3 value was converted from 100 μg/m^3.

Compared to WHO Air Quality Guideline values for $PM_{2.5}$, the number of days where these were exceeded (2012-2016) were 1,083 in Saraburi province, 857 in Chiang Mai and 232 in Songkhla. The number of days where values exceeded the WHO PM_{10} guidelines values were 1,614 for Saraburi, 558 for Chiang Mai and 258 for Songkhla. For ozone, the WHO guideline value equivalent was exceeded 74 days for Songkhla, and 8 and 6 days, respectively, for Saraburi and Chiang Mai.

For the relative risk data (RR>1.0), the data shows that:

- For ozone, Songkhla had a much higher number of cases (112) of significant relative risk (RR>1.00) associated with health effects than the other two provinces (Chiang Mai, 69; Saraburi, 11).
- For ozone, in Songkhla, the greatest number of significant health observations (RR>1.00) across age groups were seen for J00-J06 - acute upper respiratory infections and J30-J39 - other diseases of the upper respiratory tract (13 each). This is similar for Chiang Mai, where the greatest number of significant health observations (RR>1.00) across age groups were seen for J00-J06 - acute upper respiratory infections (13). However, interestingly, in Saraburi, which had the fewest number of significant health observations (RR>1.00) across age groups associated with ozone, the greatest number of significant health observations were seen for I80-I89 - diseases of veins, lymphatic vessels and lymph nodes not elsewhere classified and J09-J18 - influenza and pneumonia (2 each).

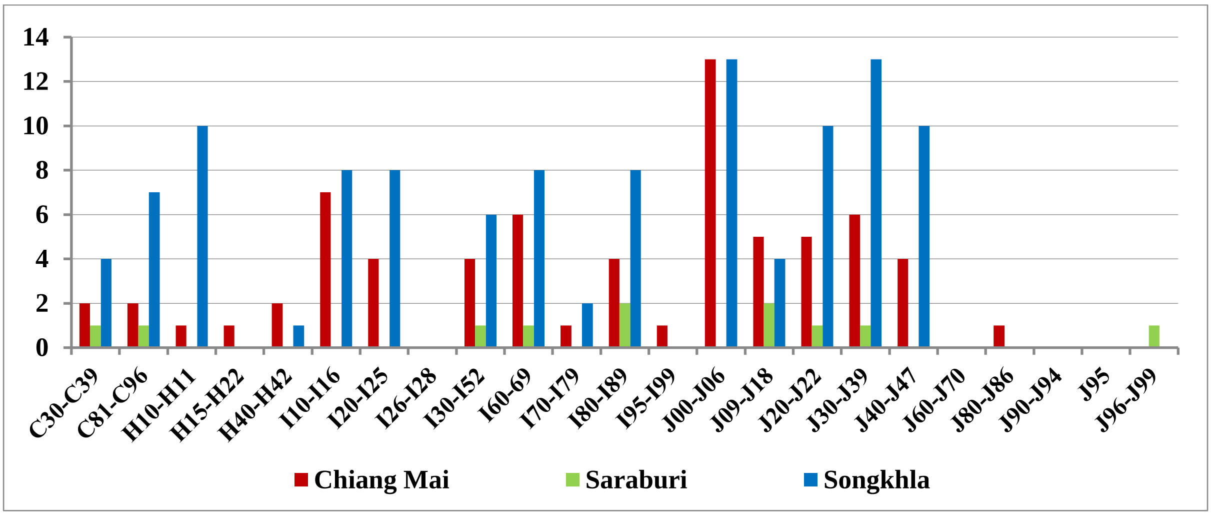

Figure 13. Significant observations (RR>1.0) by ICD-10 for Ozone.

- In terms of health observations (RR>1.00) by age group for ozone across the 3 provinces, the greatest significant observations were seen for the 60+ age group (28), 55-59 age group (23), and the 45-49 age group (20).

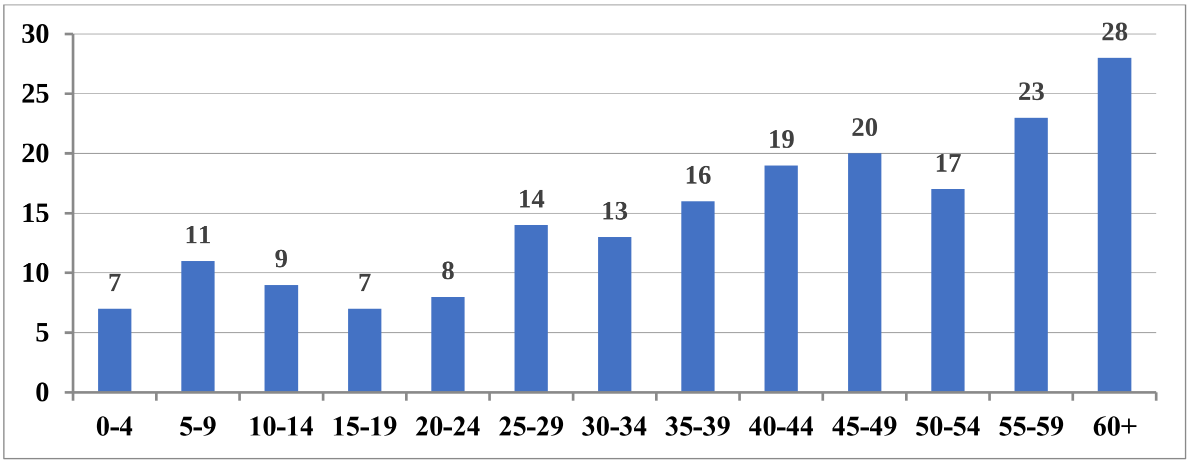

Figure 14. Significant observations (RR>1.0) by age group for ozone.

- For $PM_{2.5}$, Songkhla (34) had the greatest number of significant health observations (RR>1.00), followed by Saraburi (26) and Chiang Mai (17).
- For Saraburi, the greatest number of significant health observations (RR>1.00) across age groups were seen for I60-I69 - cerebrovascular diseases and J00-J06 - acute upper respiratory infections (5 each), C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue and J90-J94 - other diseases of the pleura (3 each), C30-C39 - malignant neoplasms of respiratory and intrathoracic organs, I30-I52 - other forms of heart disease, I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified, and J40-J47 - chronic lower respiratory diseases (2 each).

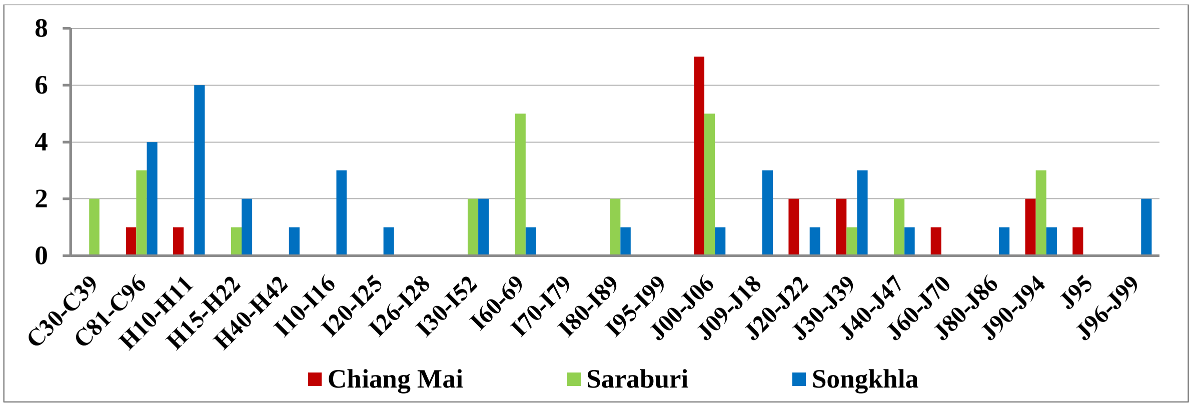

Figure 15. Significant observations (RR>1.0) by ICD-10 for $PM_{2.5}$

- In terms of health observations (RR>1.00) by age group for $PM_{2.5}$ across the 3 provinces, the greatest significant observations were seen for the 55-59 age group (10), followed by the 60+ age group (10), and the 50-54 age group (8).

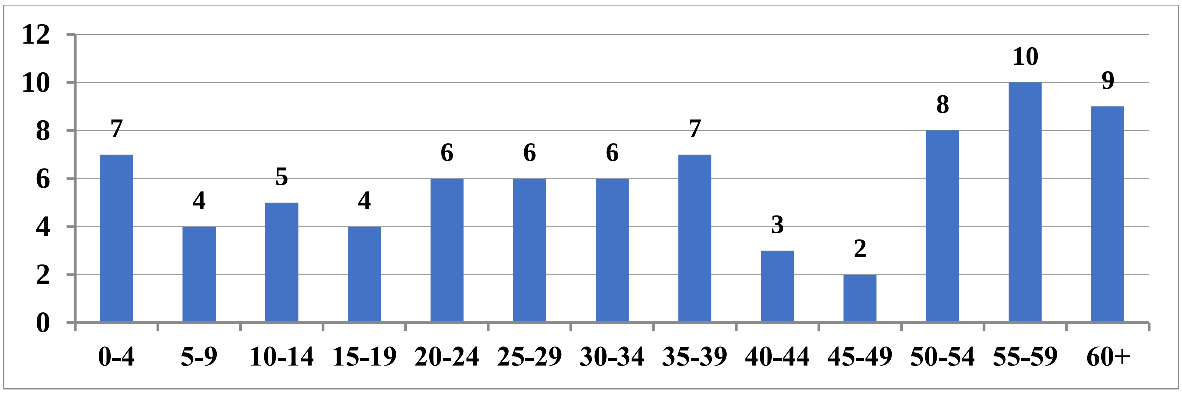

Figure 16. Significant observations (RR>1.0) by age group for $PM_{2.5}$

- For PM_{10}, Saraburi (66) had the highest number of significant health observations (RR>1.00) across age groups, compared to Songkhla (35) and Chiang Mai (26).
- In terms of the increased relative risks associated with PM_{10}, Saraburi had the greatest number of observations for J00-J06 - acute upper respiratory infections (12), J30-J39 - other diseases of the upper respiratory tract (9), J40-J47 - chronic lower respiratory diseases (8), I10-I16 - hypertensive diseases (7), J20-J22 - other acute lower respiratory infections (6), I60-I69 - cerebrovascular diseases (5), I20-I25 - ischemic heart diseases and I30-I52 - other forms of heart disease (4 each), C30-C39 - malignant neoplasms of respiratory and intrathoracic organs (3), and C81-C96 - malignant neoplasms of lymphoid, hematopoietic and related tissue and I80-I89 - diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified (2 each). Songkhla had the greatest number of observations for I20-I25 - ischemic heart diseases (6), C81-C96 - other diseases of the upper respiratory tract (5), and I10-I16 - hypertensive diseases (4). Chiang Mai had the greatest number of observations for J00-J06 - acute upper respiratory infections (8), and I10-I16 - hypertensive diseases and J30-J39 - other diseases of the upper respiratory tract (4 each).

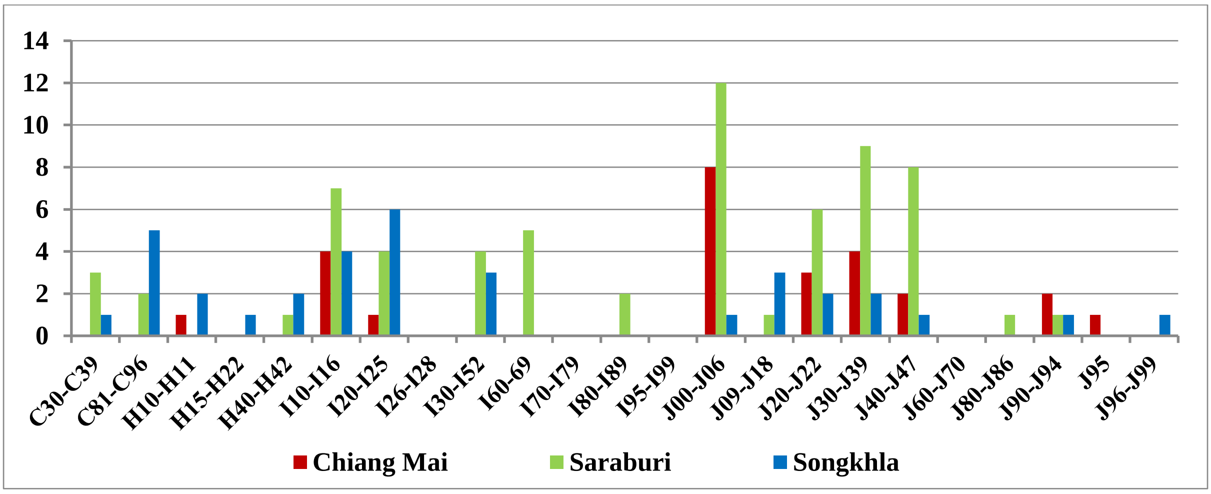

Figure 17. Significant observations (RR>1.0) by ICD-10 for PM_{10}

- In terms of health observations (RR>1.00) by age group for PM_{10} across the 3 provinces, the greatest significant observations were seen for the 60+ age group (21), followed by the 50-54 age group (19), and the 55-59 age group (14).

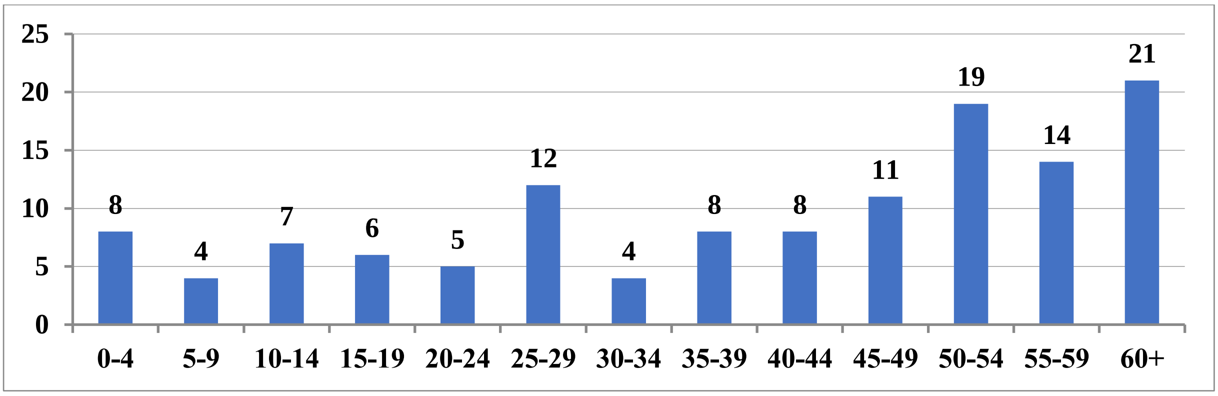

Figure 18. Significant observations (RR>1.0) by age group for PM_{10}

- In terms of comparison across pollutant type, looking at all 3 provinces, the greatest number of cases of elevated relative risk (RR>1.00) associated with exposure was seen with ozone (192), followed by PM_{10} (127), and then $PM_{2.5}$ (77).

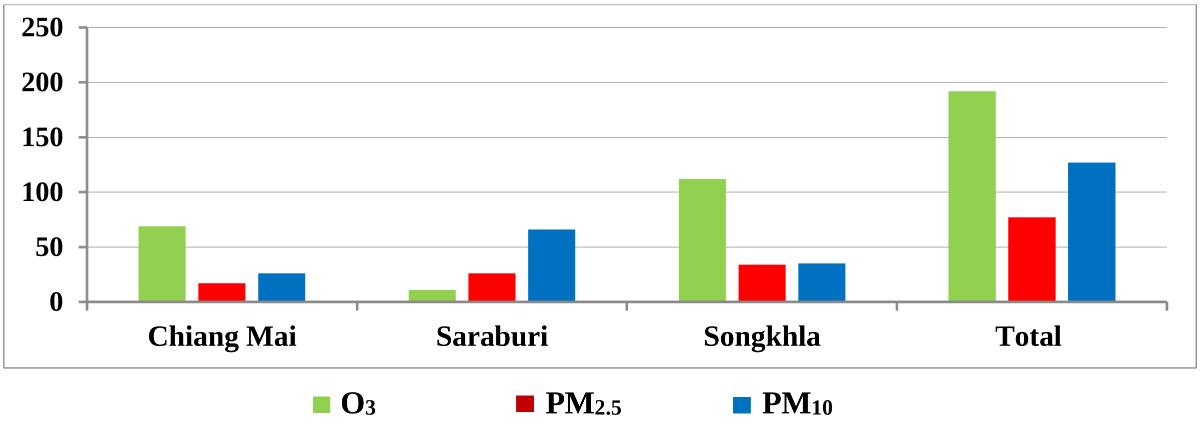

Figure 19. Significant observations (RR>1.0) by pollutant

When looking at the DALYs (Table 16), the greatest number of DALYs, i.e. largest health impacts, were seen with Songkhla (150.6-264.2 years per 1,000 population), followed by Saraburi (77.9-317.1 years per 1,000 population) and then Chiang Mai (32.8-176.1 years per 1,000 population). Saraburi is well known for stone mining and processing, while Chiang Mai air quality is affected mainly by open burning. Air pollutant sources in Songkhla are less well-defined, and therefore more studies are needed to pinpoint the sources as targets for remediation. Again, it should be noted that the upper bound of the DALYs for Saraburi (317.1 years per 1,000 population) is higher than that of Songkhla (264.2 years per 1,000 population).

In terms of data quality, for the air pollutant monitoring data from the Pollution Control Department (PCD), one of the key problems is missing data for significant periods of time for all the pollutant data used in the analysis. Generally, in these cases, there are statistical techniques that can be employed to impute the missing data points, if there are adequate data for the imputation procedure. However, for the data set used in this analysis, data was missing for a significant period of time, i.e. between a minimum of a full month to a maximum of a whole year. PCD personnel stated that the reasons for long periods of missing data were mainly power outage and problems in maintenance and management of the air monitoring stations

(Pollution Control Department, personal communication). These do not fit into any of the four "Missingness Mechanisms" (Gelman and Hill, 2007), and therefore it is not possible to infer these missing values from the available data, even with the most elaborate and sophisticated statistical models available. One of the major limitations resulting from large number of missing observations is that the results from the regression model will have a large degree of uncertainty, and this is also true for subsequent analyses based on the results from the model. For the outpatient department (OPD) data from the Ministry of Public Health (MoPH), the data quality was excellent. According to the liaison from the MoPH, the database was elaborately built and can retrieve recorded details that are needed for the analysis. The only limitation of the data from the MoPH is that there is no data from the private healthcare system (i.e. private hospitals). Currently, there is no legislation that requires any private healthcare establishment to submit any health statistics to the local, regional or central database. In other words, with healthcare data, there is an entirely other class of missing data, which might or might not be able to be imputed by any statistical technique. This unknown quantity of patients might also otherwise significantly contribute to the observed effect of air pollutant exposures on health outcome. However, since we have no data on this, we cannot accurately estimate the effect. Currently, GLM for Poisson family calculations disregard all the data points with missing values. This study did not evaluate appropriate data imputation strategies for both health and pollutant data. Therefore, only complete cases were used in model calculations. This will contribute to any inaccuracy of the results from the model. Additionally, weather parameters, such as humidity, wind speed, and atmospheric pressure at each of the air monitoring stations were not made available by the PCD. This could make the model inaccurate to some extent, but we cannot exactly quantify the accuracy of the model. Other seasonal trends, such as long weekends, flu seasons, and other infectious disease outbreaks were also not included in the model. The rationale for not using all the predictors in one model was that we assumed that these pollutants were coming from a single source, which is automobile exhaust. However, the actual situations are always more complex than the model used in any study. Another point is that each district is a unique case all of its own, and it will not be possible to study different districts by using the same model with the same parameters and assumptions.

The comparisons that can be made with the available data is the comparative relative risks for the various health effects categories associated with the three different air pollutants across the three provinces. To reiterate, the three provinces were selected based on differing exposure scenarios related to different activities and thus exposure sources. Chiang Mai in the norther part of Thailand is known to be affected by air pollutants from open burning and geological features (mountains) that affect air flow and trap pollutants. Saraburi in the central part of the country is known to have stone mining and processing activities that can be important sources of pollutants. Songkhla in the southern part of Thailand was chosen for being a supposedly less polluted area.

The relative risk estimates generated by the aforementioned model were likely impacted by the inaccuracy caused by limited data. As previously stated, there were long periods of time for which there was no data. One limitation of the statistical software used in this assessment is that incomplete data on the same date entries will be discarded. For example, if OPD data from Jan 2012 - June 2012 were present but $PM_{2.5}$ monitoring data were not present in the same period of time, the model would discard the health data of Jan 2012 – June 2012 to match the $PM_{2.5}$ monitoring data. This was the main source of the uncertainty in the model. This begs the question as to whether the small effect, i.e. relative risk of 1.01, is a real effect. From a statistical point of view, statistically significant results usually come from either large effect with high uncertainty from small numbers of data points, or small effects with low uncertainty from a large number of data points. In this case, the numbers of data points are considered large enough that small effects are deemed statistically significant. The next question is whether other non-statistically significant results were real effects. Although we cannot say for certain that we would see adverse health consequences from high levels of pollution because the data were missing, we speculate that if the data were available, we would see more significant effects of the pollutants on health outcomes of interest. Note that this is purely speculative from the trends we observed, and further studies are needed to complete the gaps in our understanding of the pollutant effects on health outcomes in Thailand.

CONCLUSIONS

In this report, relative risks associated with increased exposures to 3 selected air pollutants – $PM_{2.5}$, PM_{10} and ozone – were calculated based on air quality and health monitoring data in 3 provinces in Thailand over a period of 5 years (2012-2016): Chiang Mai, Saraburi and Songkhla provinces. Disability-adjusted life years (DALYs) were also calculated for each of the provinces as a sum total of the DALYs for each of the ICD-10 disease classifications. Subsequently, the predicted size of the populations in the 3 provinces affected by the levels of exposure to the 3 aforementioned air pollutants at levels greater than the national standards were estimated. Finally, an estimate of the economic benefits from various levels of environmental management (reduction in exposure concentrations to the WHO Interim Targets 1, 2 or 3, or to below the WHO Guideline values) was calculated for all three provinces. Economic benefits were estimated to total 1.86 billion (Interim Target 1), 2.10 billion (Interim Target 2), 2.13 billion (Interim Target 3), and 2.18 billion (reduction to below WHO Guideline values) Thai Baht for Chiang Mai province; 2.54 billion (Interim Target 1), 2.63 billion (Interim Target 2), 2.70 billion (Interim Target 3) and 2.73 billion (reduction to below WHO Guideline values) Thai Baht for Saraburi province; and 1.48 billion (Interim Target 1), 1.12 billion (Interim Target 2), 1.30 billion (Interim Target 3) and 1.30 billion (reduction to below WHO Guideline values) Thai Baht for Songkhla province for reduction of $PM_{2.5}$ and PM_{10} levels. With the potential economic benefits estimated, what is needed is a cost analysis to determine at which remediated exposure levels the benefits would significantly outweigh the management/implementation costs.

The situational analysis conducted for Thailand, and the study on the association between air pollutant levels and various health effects, has shown that there are certain inefficiencies and factors leading to elevated health risks associated with air pollution that need to be addressed. First, it is clear that the sources of air pollutants present in the country is quite varied across different locations, e.g. Chiang Mai versus Saraburi, which means that there is no single policy recommendation that can be made to cover all situations. Awareness of the local situation, and policies specific for those sources and situations are required. Second, health data collected at the Ministry of Public Health is not complete. This is because there are hospitals and health care services, e.g. clinics, that are not within the data collection system of the Ministry of Public Health. Many of these hospitals, e.g. private and university hospitals, do collect their own data, but much of this is not submitted to the Ministry of Public Health, and the data collection systems are not equivalent or compatible, e.g. different types of data collected and different codes used, etc. Classification of cases of morbidity and, in particular, mortality may also not be accurate in terms of the actual primary cause, which means that important links are potentially lost. Third, the data would tend to indicate not only variability in risk due to local emission sources, but also variability in risk to certain sensitive sub-populations, e.g. people 60+ years of age, which means that these sensitive sub-populations may need to be under special consideration for any policy measures.

POLICY RECOMMENDATIONS

With the conclusions from this study in mind, the following policy recommendations are proposed:

1. **Control and minimization of air pollutant emissions at the source**
   - Increasing awareness, for example through generation of new knowledge and/or understanding, on health impacts of air pollution.
   - Make the data/information available, and accessible, to the public, as well as to all business owners and regulatory authorities involved.
2. **Increasing effectiveness of control measures**
   - Review, and revise as needed, national air quality standards, taking into consideration impacts on health and susceptible populations.
   - Review, and revise as needed, standards for air pollutant emissions, taking into consideration local "carrying" capacities, and air quality standards for specific locations, e.g. Na Phra Lan district of Saraburi province.
   - Build capacity of local governing bodies for management and control of air pollutant emissions.
3. **Improving management of air pollution**
   - Develop a system for health data collection
     - A system for correct/accurate/appropriate disease diagnosis and categorization for cases of morbidity and mortality, especially in emergencies.
     - Initiate/improve collaborations with private hospitals, and those under the jurisdiction of the Ministry of the Interior or universities, such that morbidity and mortality data are reported to the Ministry of Public Health.
4. **Other (e.g. information dissemination)**
   - Integrate health and environmental monitoring data in a national database.
   - Disseminate information on health impacts of air pollutant exposures, with focus on appropriate health protection.
   - Historical data (both hourly air pollution data and anonymized health data) should be open to the public to encourage other researchers and the general public to make full use of the data.
   - Prepare a national report on the current situation of health impacts of air pollution every two years, with one of the main aims being to clearly illustrate the linkage between health and the environment.
   - Joint organization of regular academic platforms for the discussion of the most up-to-date situation of air pollution and health impacts in the country, as well as the latest research results in this area.
   - Promote research on health impacts of air pollution, with special focus on the situation in the country. Key areas for which there is currently limited information include, for example, the use of biomarkers for monitoring exposure and effects and the socioeconomic impacts of air pollution.

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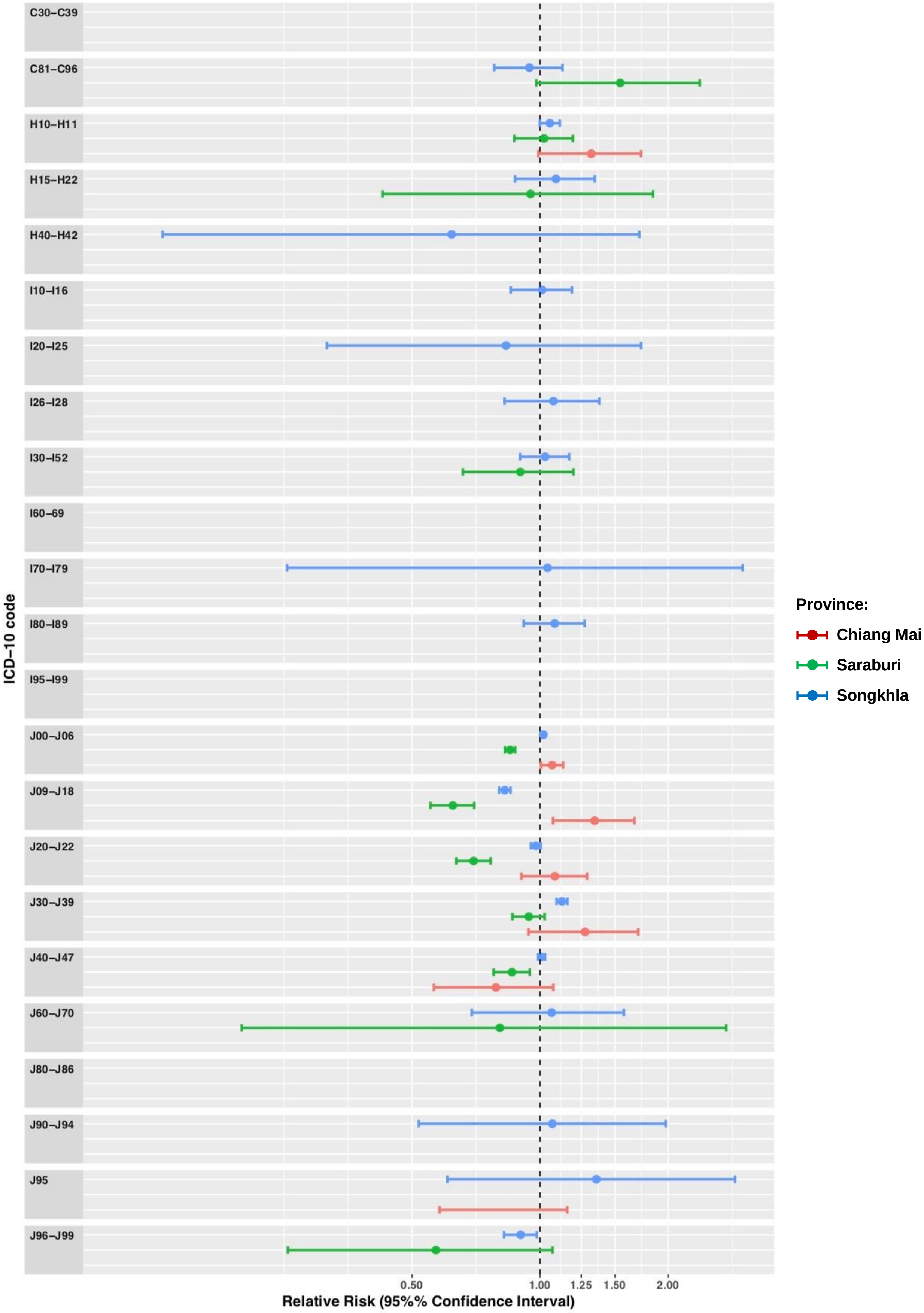
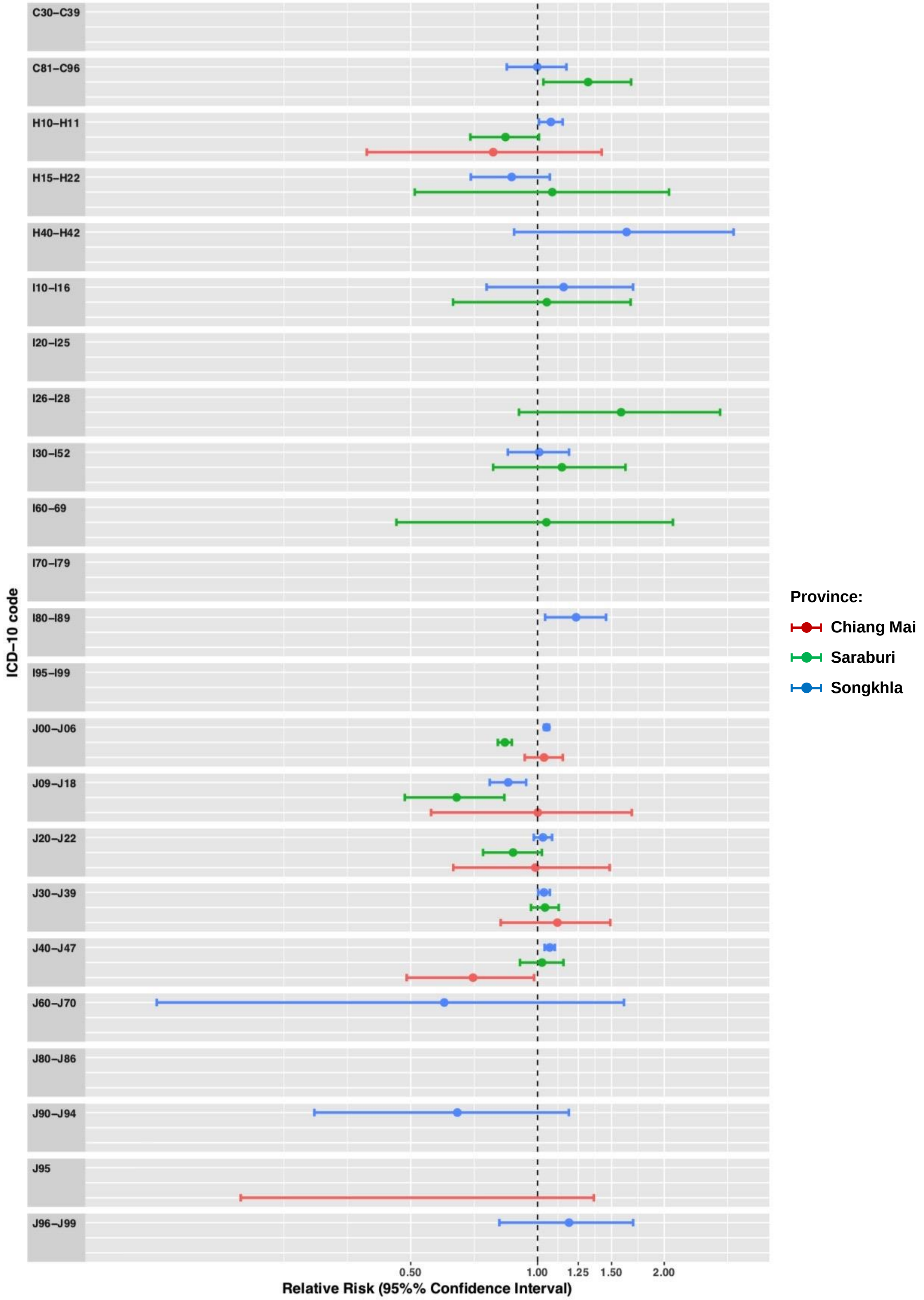
APPENDIX

Forest Plots Showing Relative Risk Per Pollutant by Age Classification

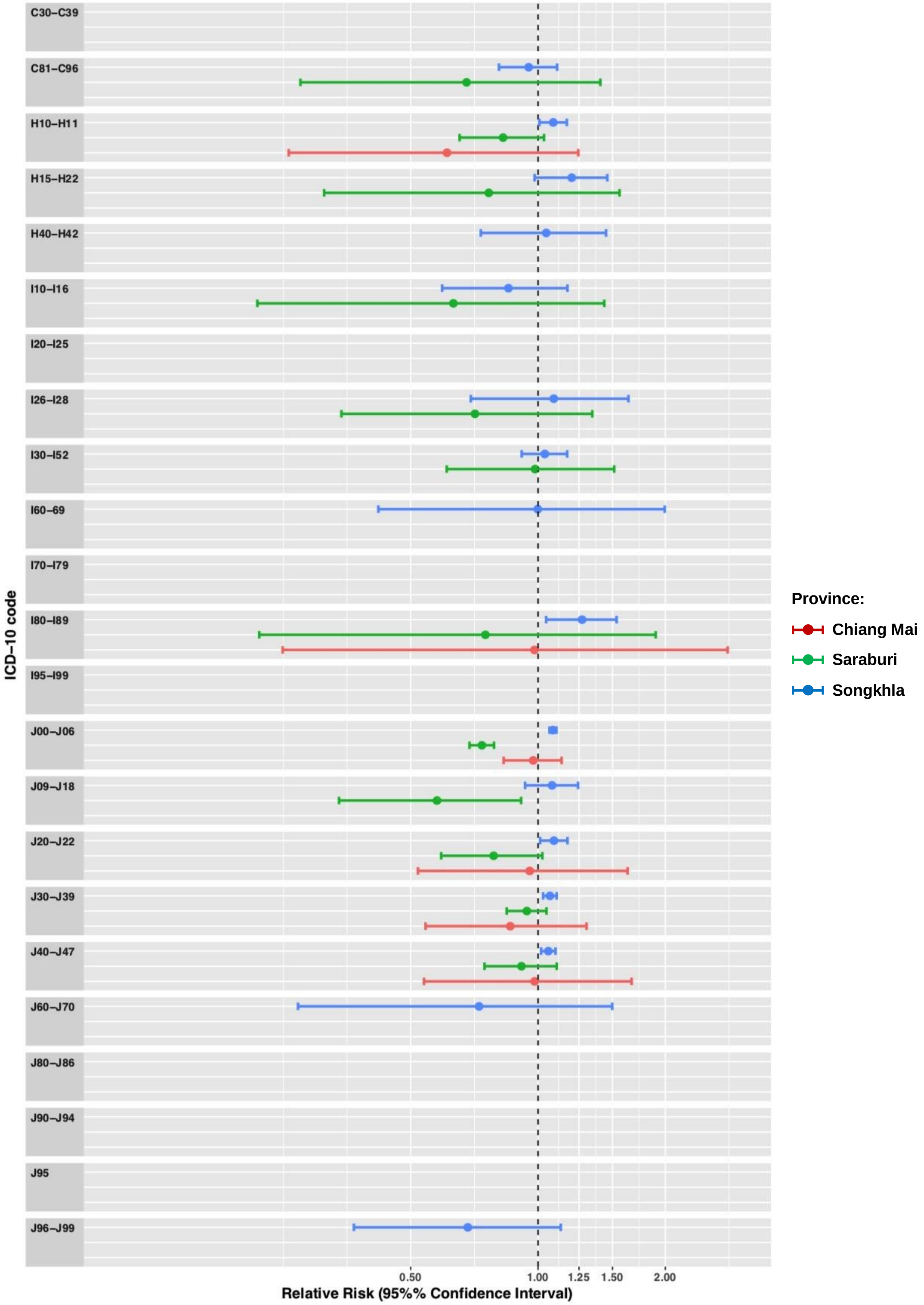
Ozone: 0-4 Age Group



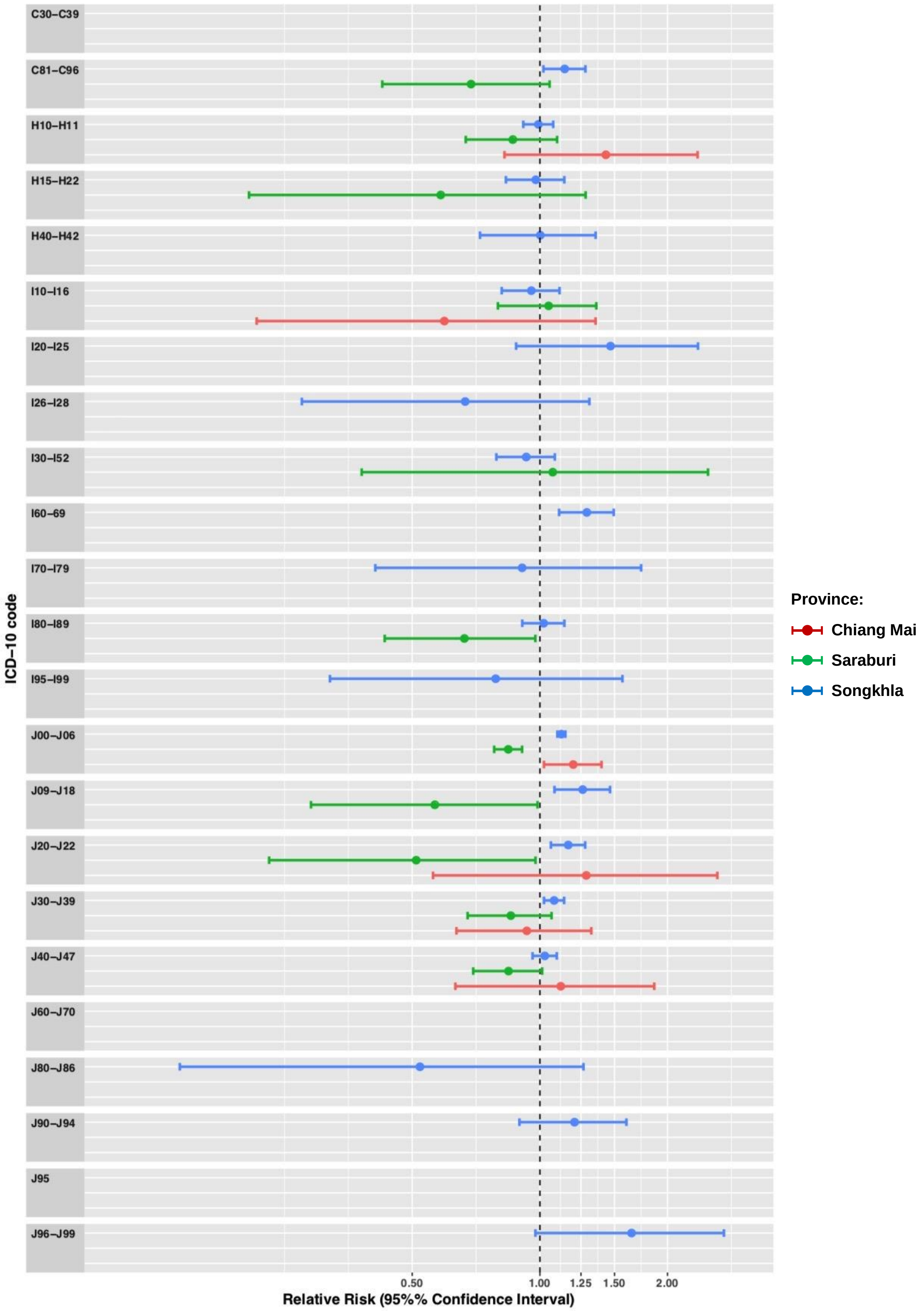
Ozone: 5-9 Age Group



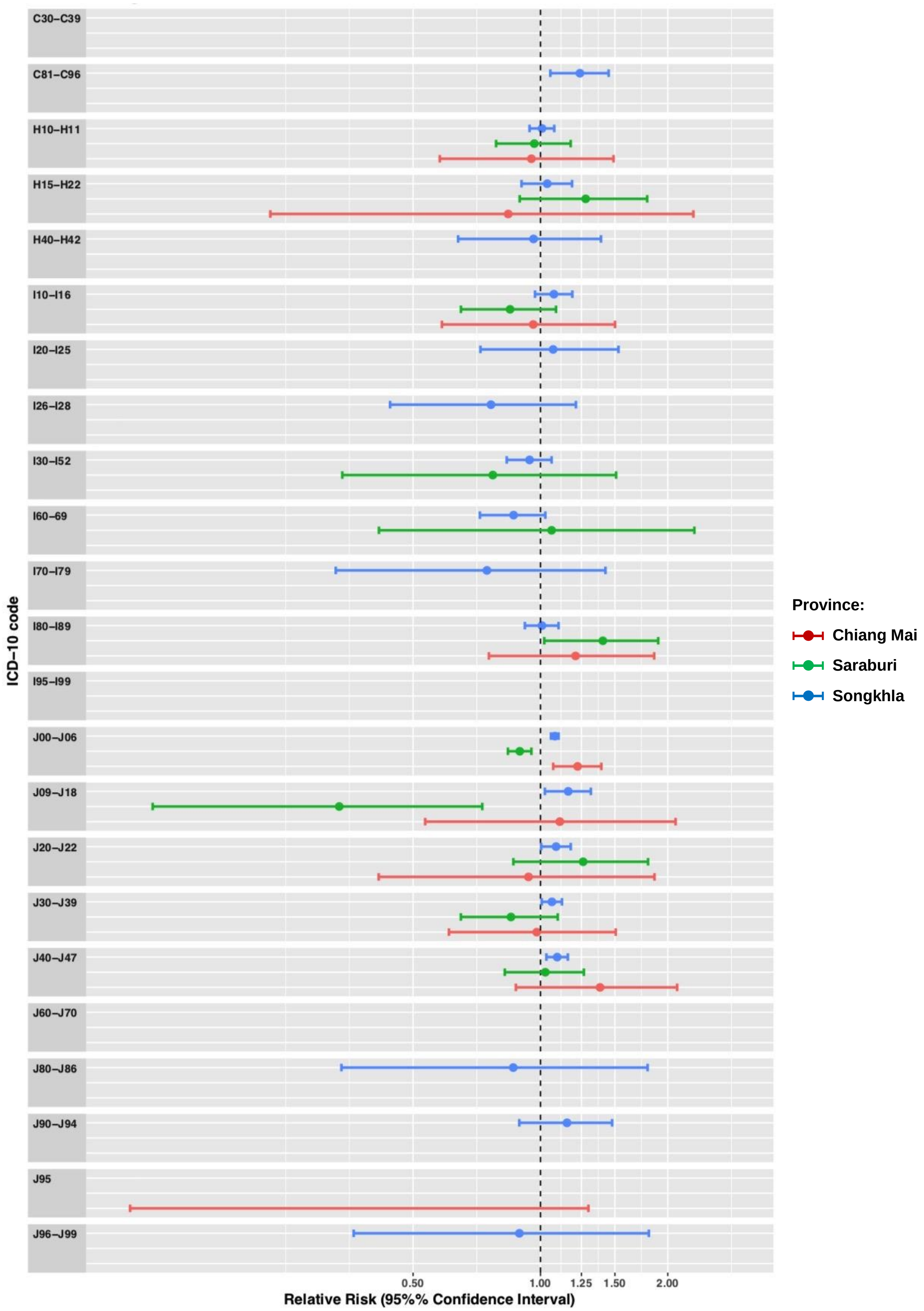
Ozone: 10-14 Age Group



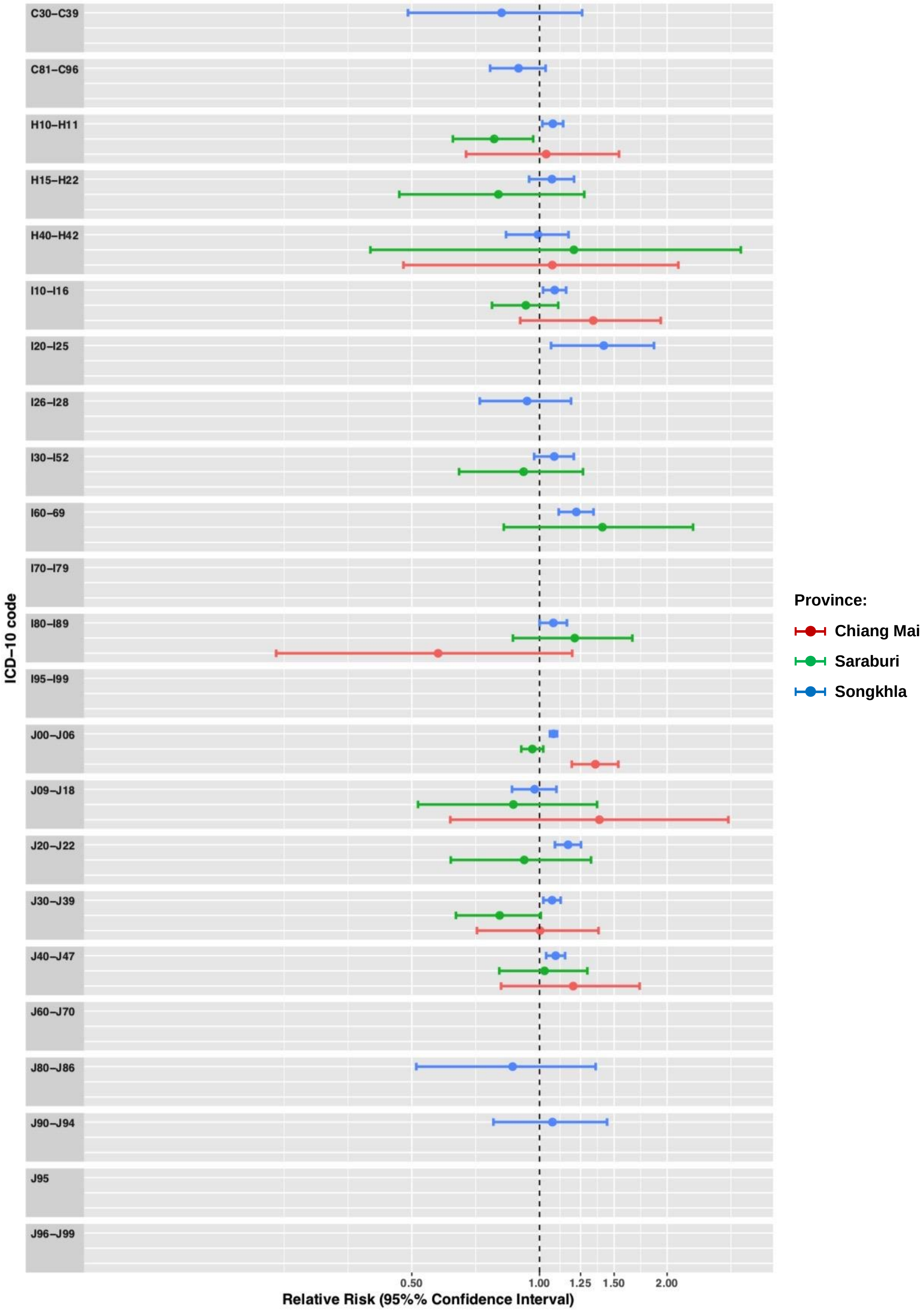
Ozone: 15-19 Age Group



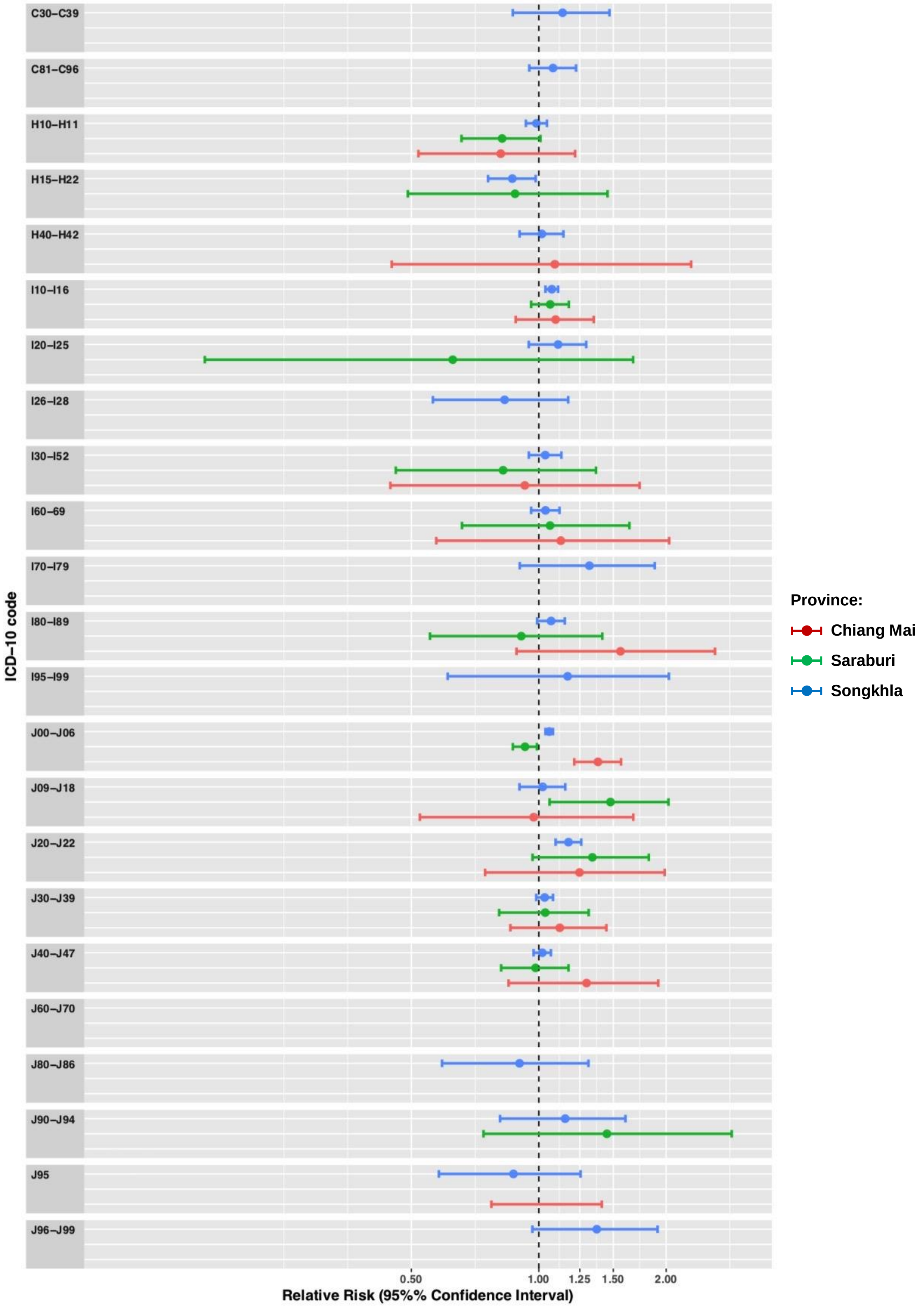
Ozone: 20-24 Age Group



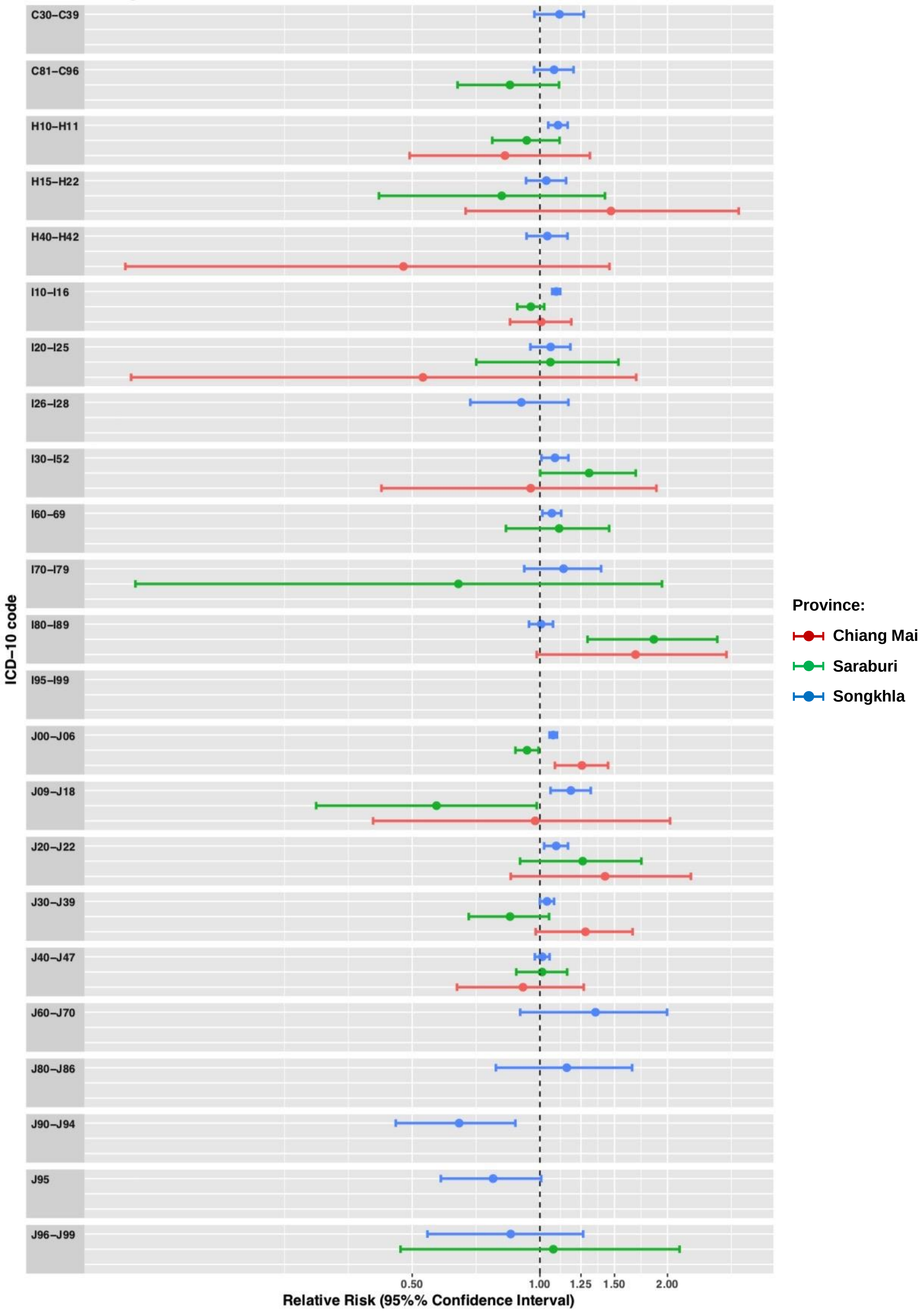
Ozone: 25-29 Age Group



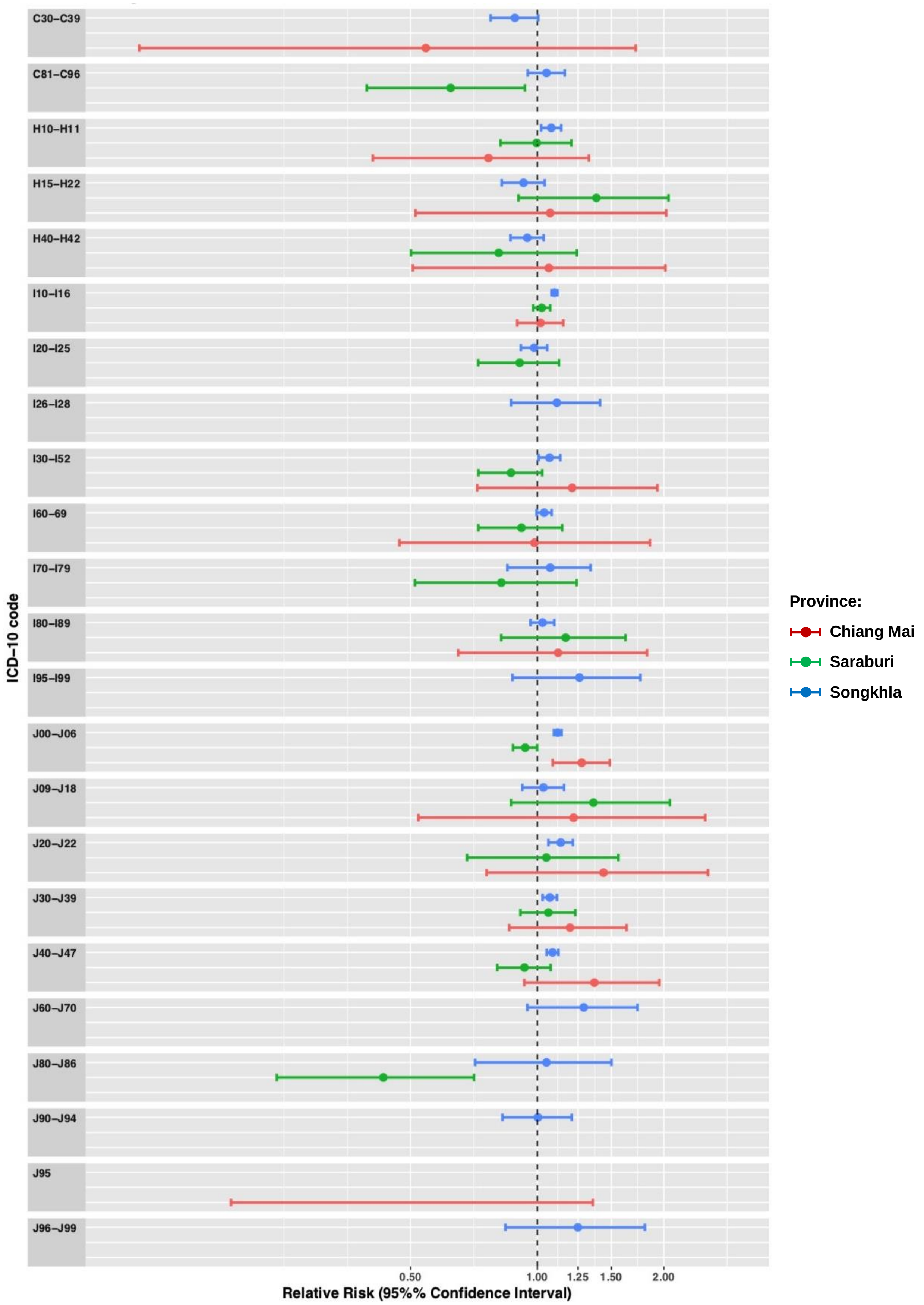
Ozone: 30-34 Age Group



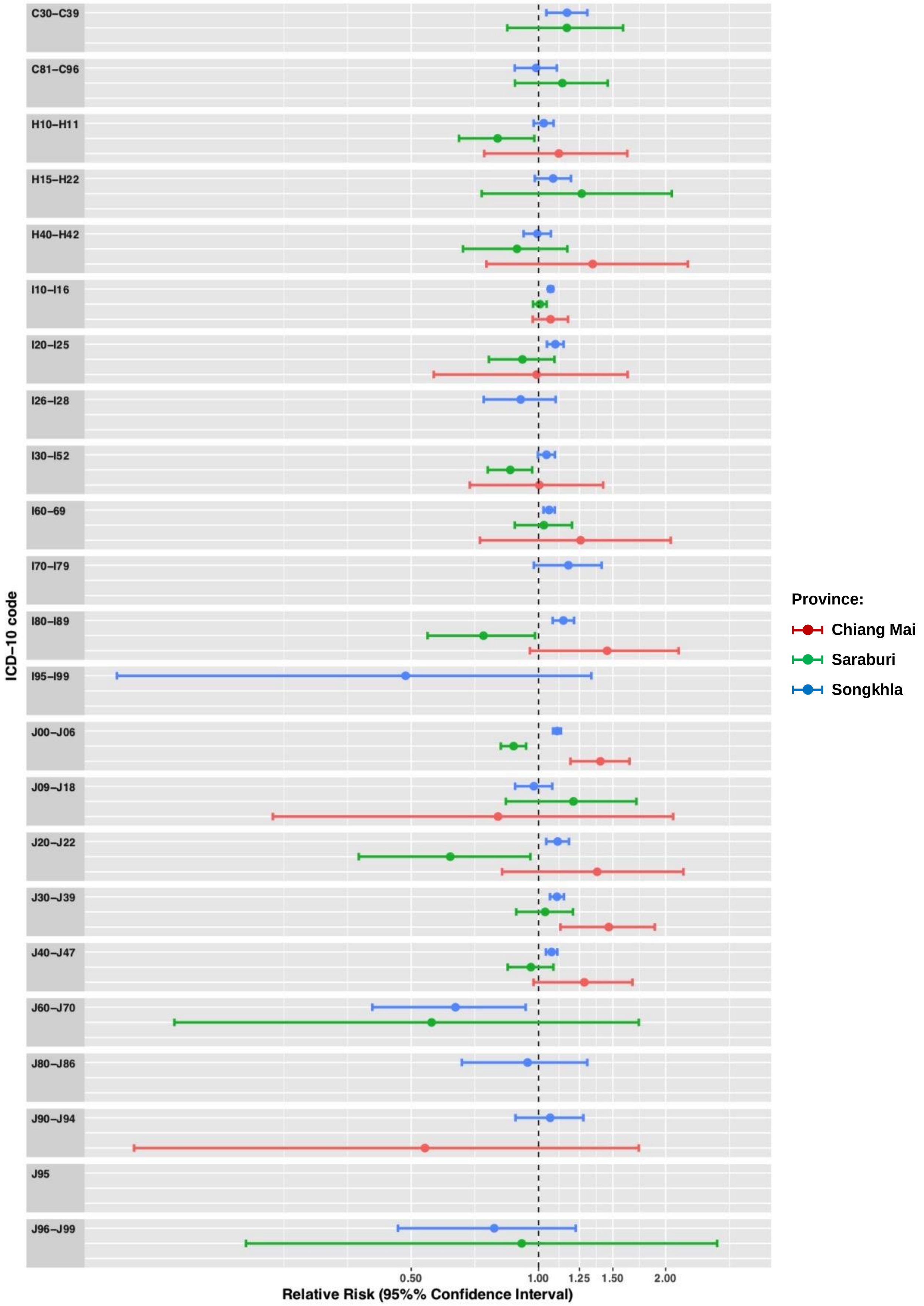
Ozone: 35-39 Age Group



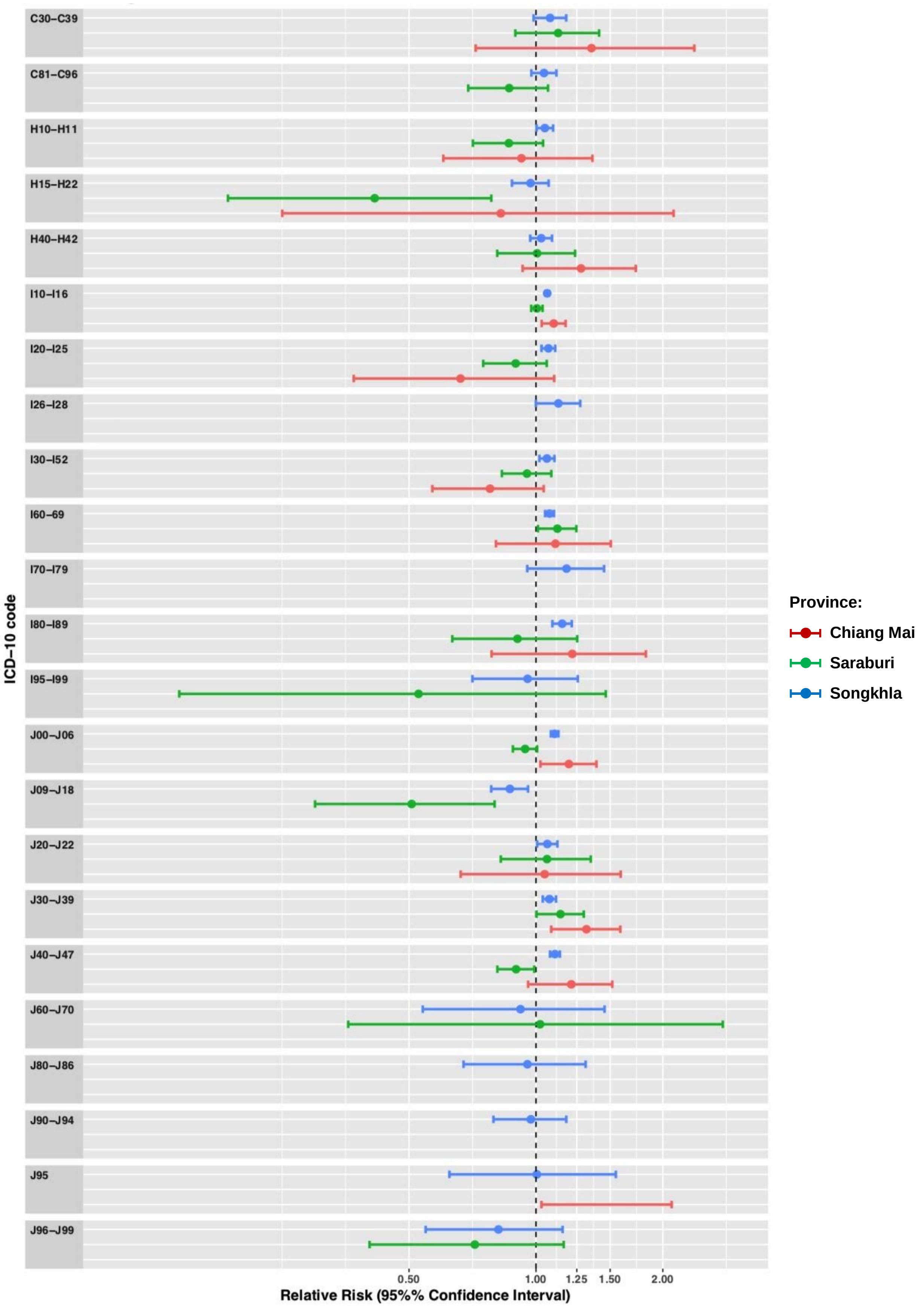
Ozone: 40-44 Age Group



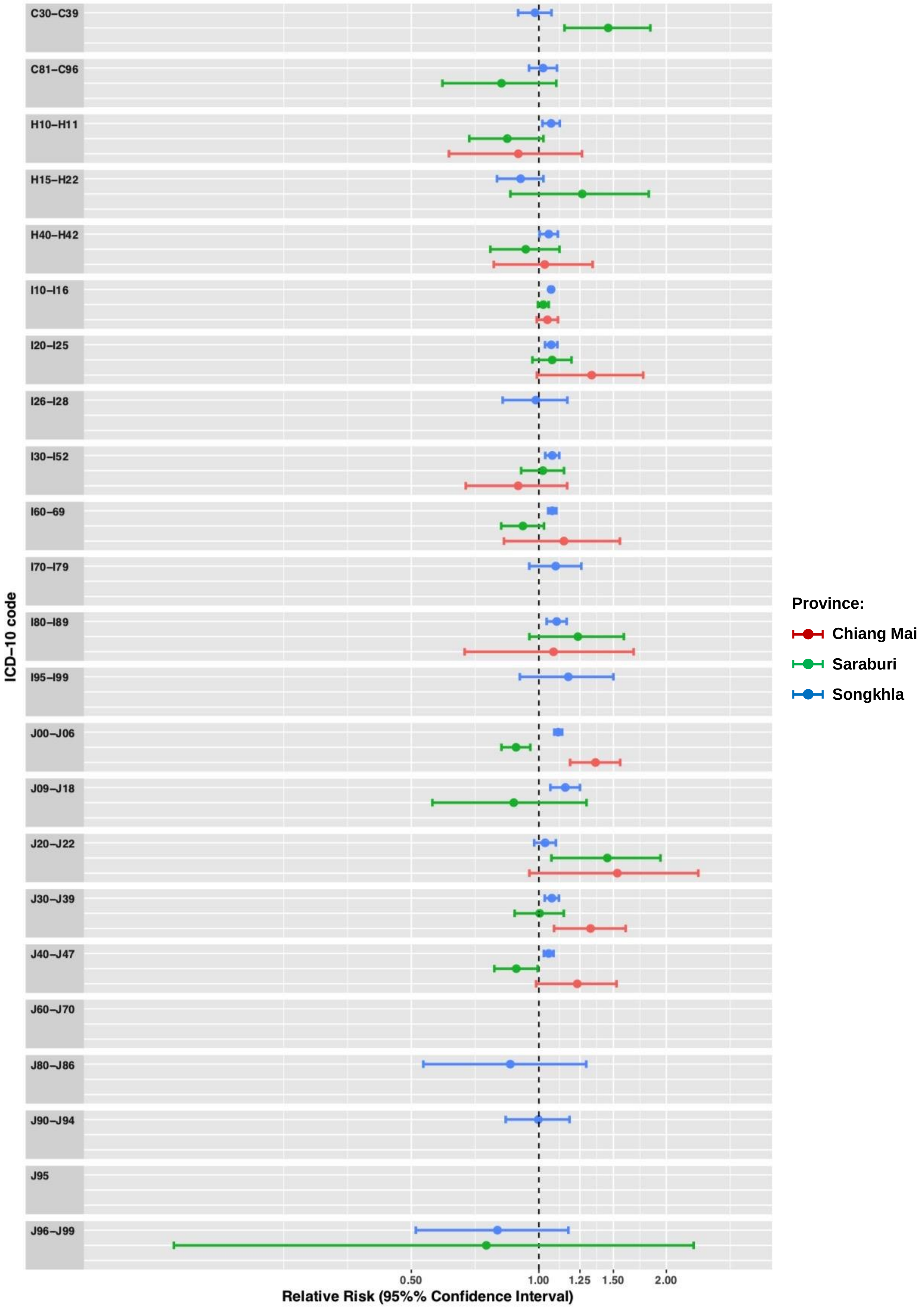
Ozone: 45-49 Age Group



Ozone: 50-54 Age Group



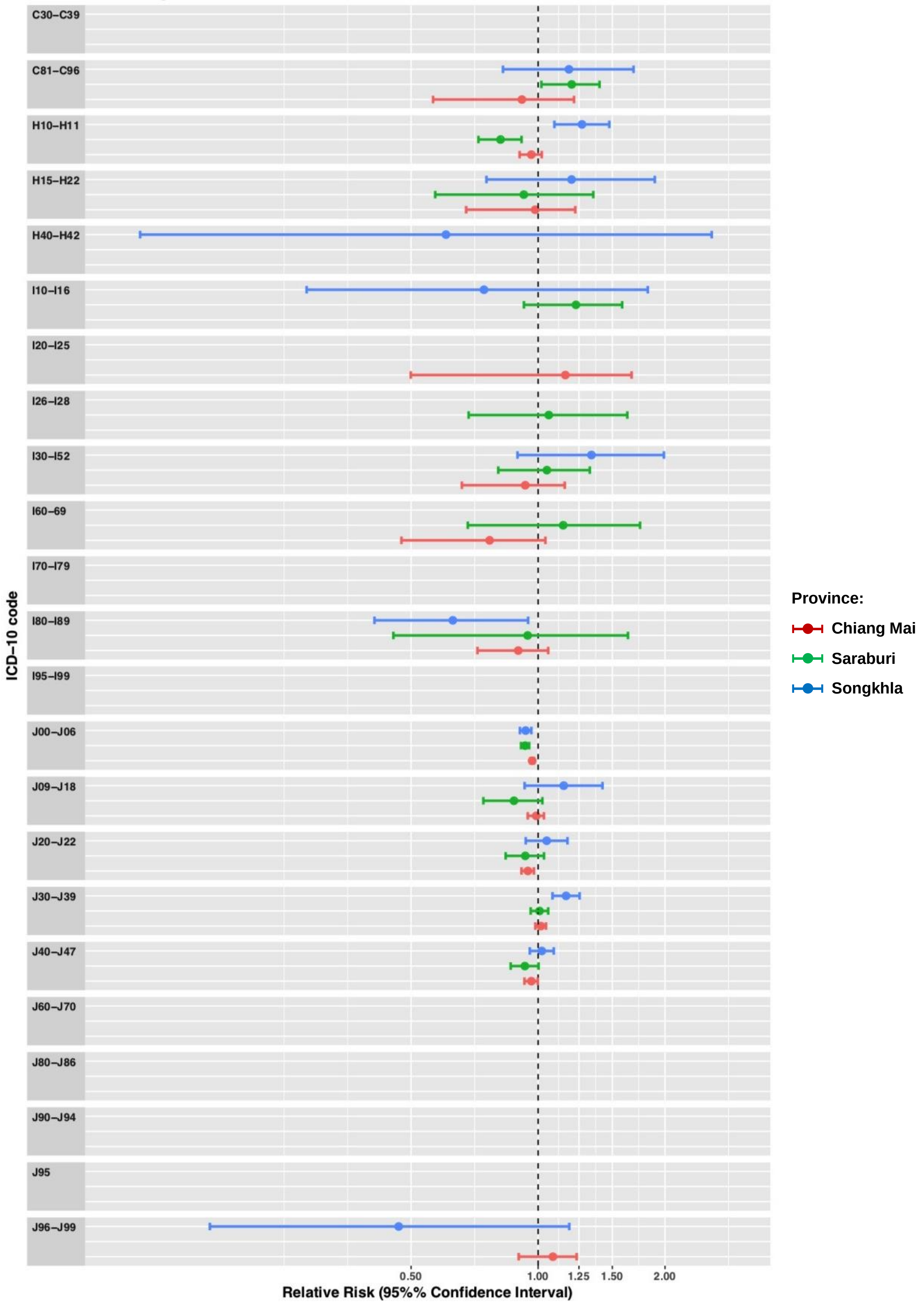
Ozone: 55-59 Age Group



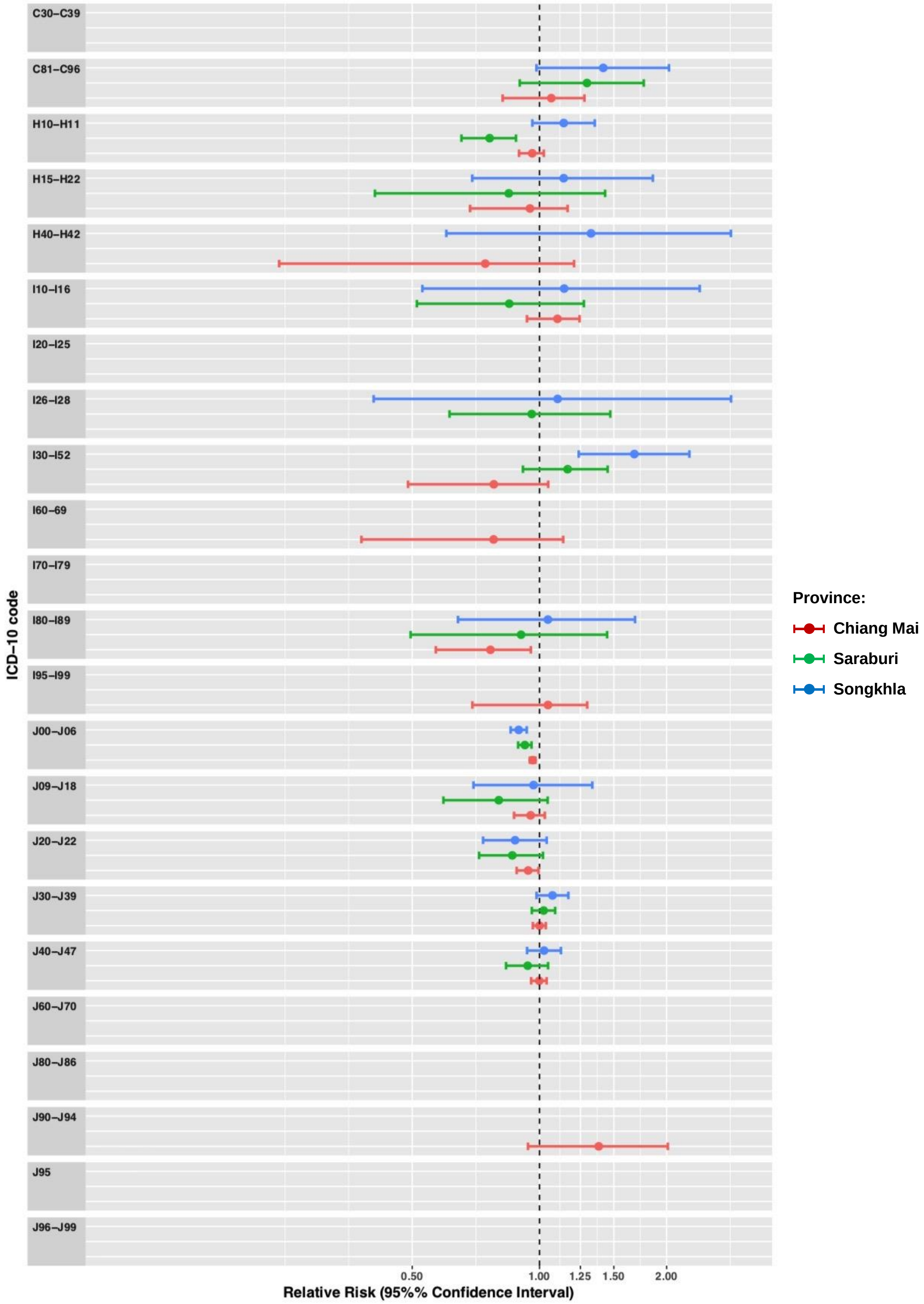
Ozone: 60+ Age Group


PM2.5: 0-4 Age Group
C30–C39
C81–C96
H10–H11
H15–H22
H40–H42
I10–I16
I20–I25
I26–I28
I30–I52
I60–69
I70–I79
I80–I89
I95–I99
J00–J06
J09–J18
J20–J22
J30–J39
J40–J47
J60–J70
J80–J86
J90–J94
J95
J96–J99
ICD–10 code
0.50
1.00
1.25
1.50
2.00
Relative Risk (95%% Confidence Interval)
Province:
Chiang Mai
Saraburi
Songkhla

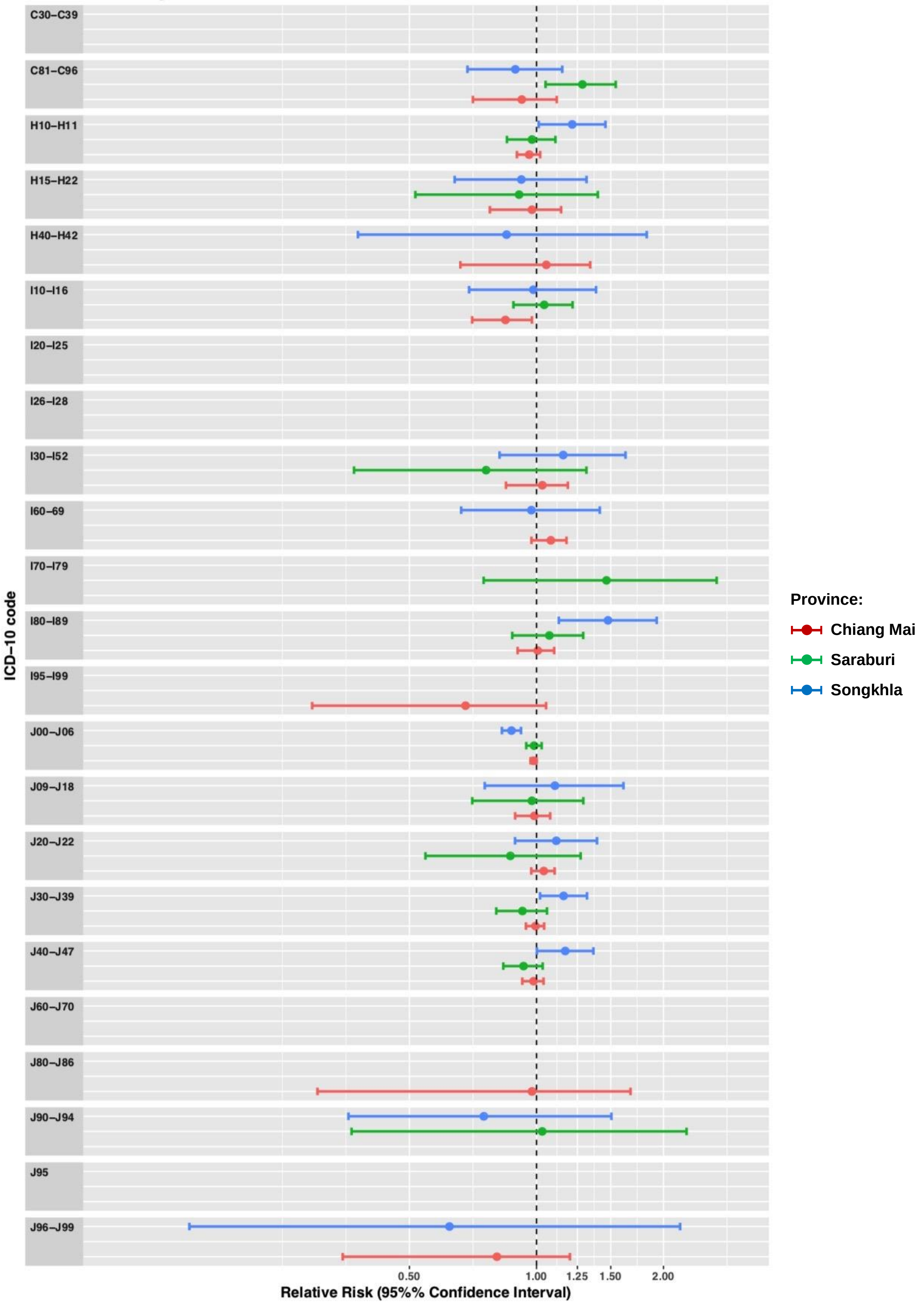
PM2.5: 5-9 Age Group



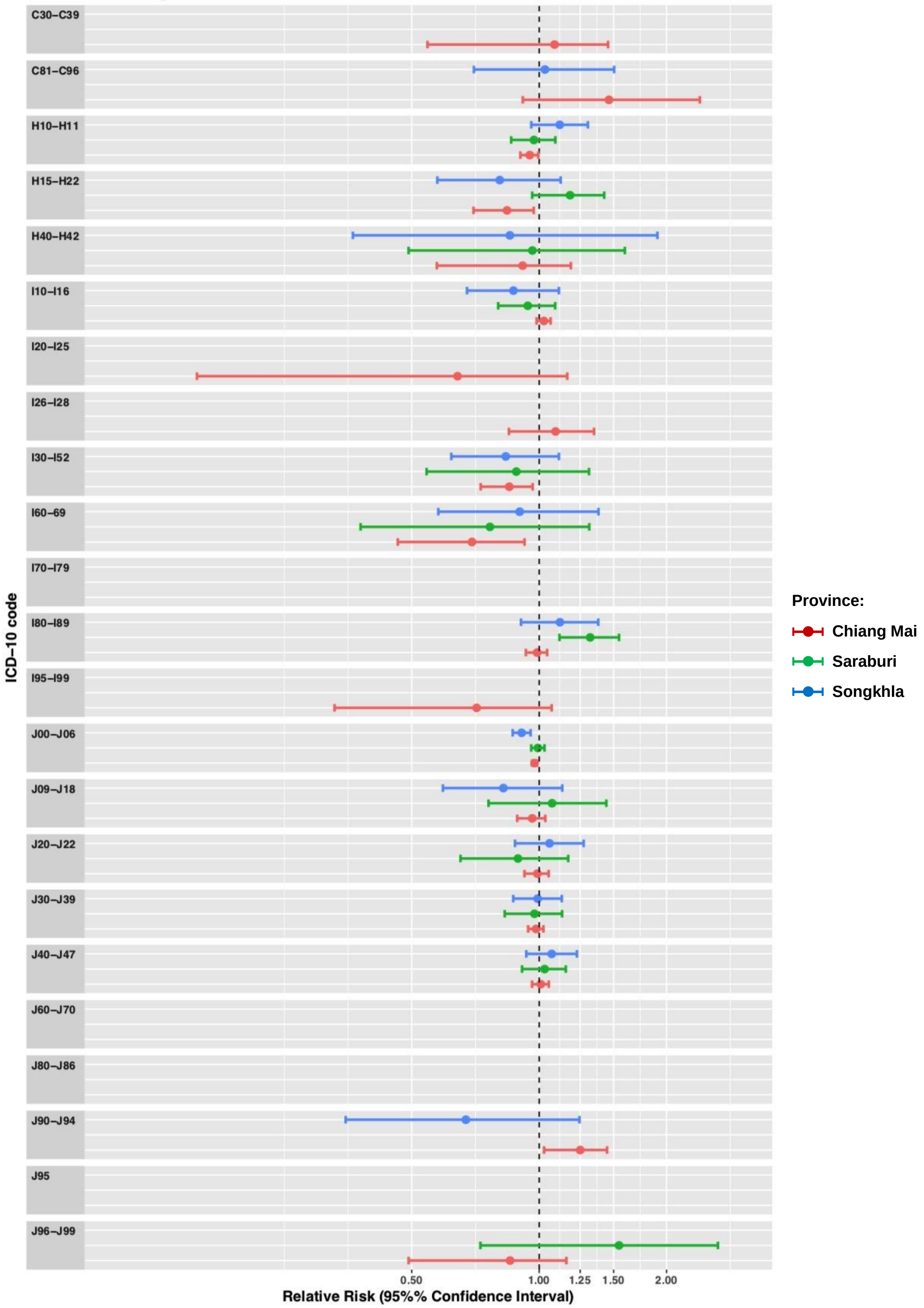
PM2.5: 10-14 Age Group



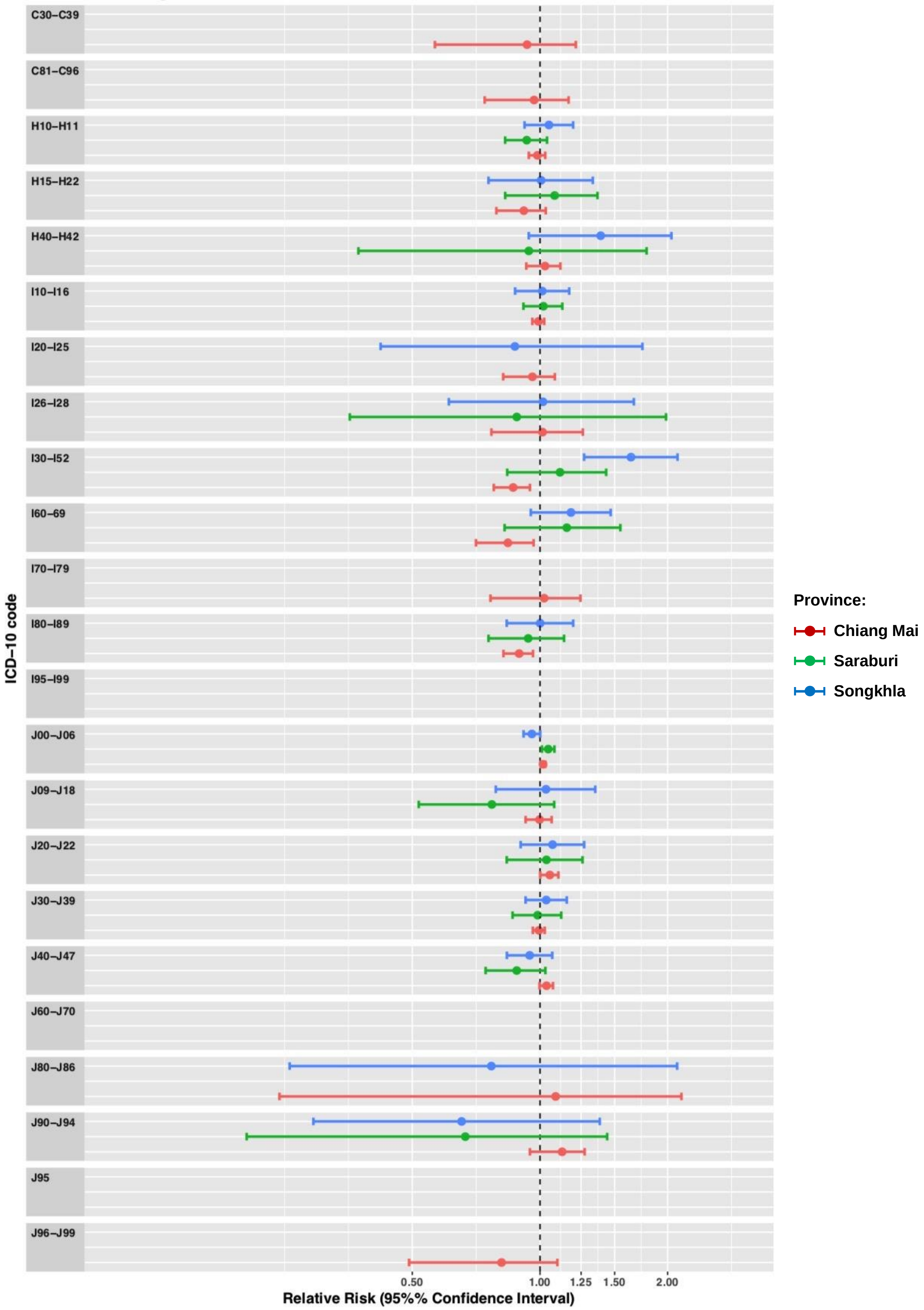
PM2.5: 15-19 Age Group



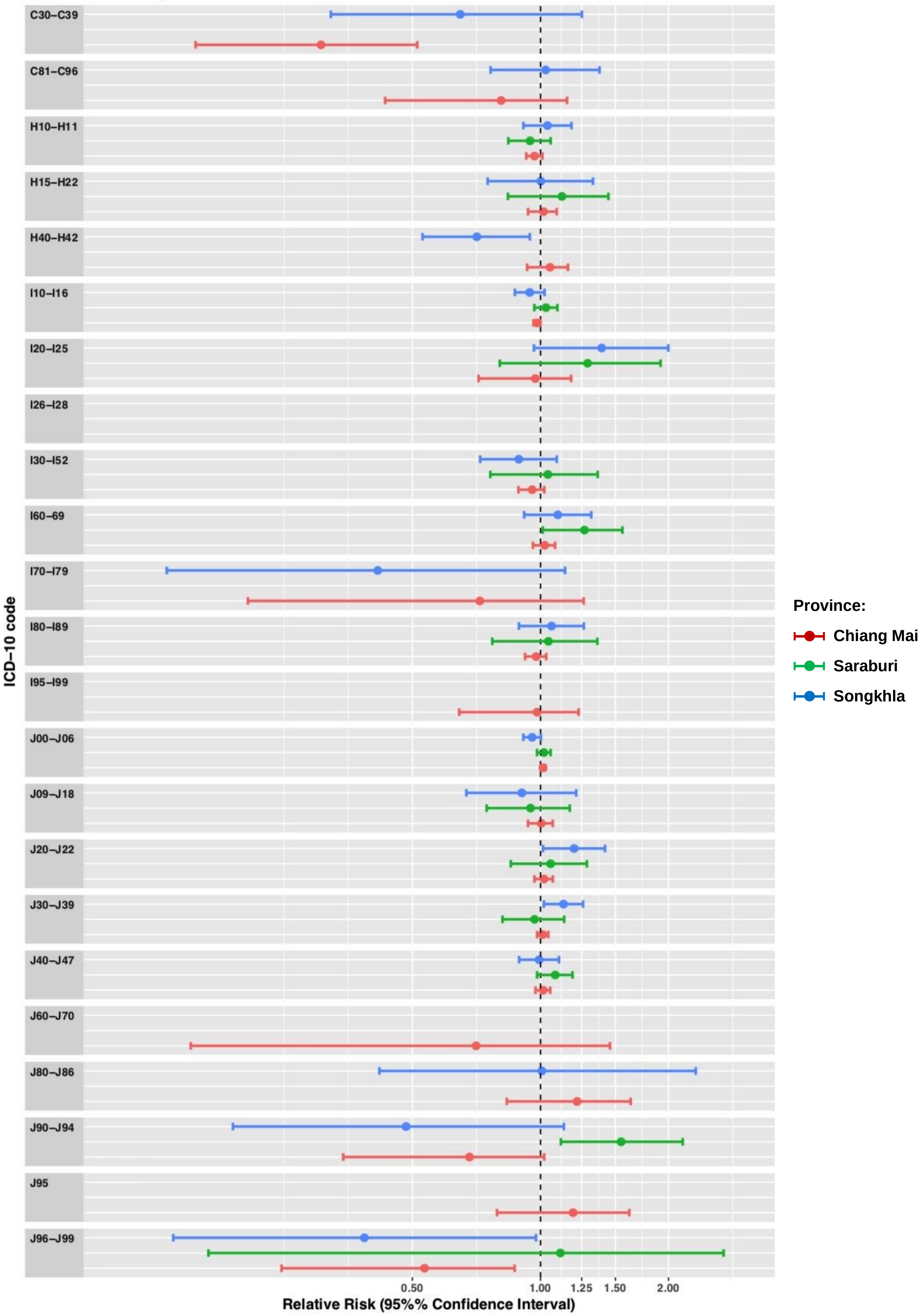
PM2.5: 20-24 Age Group



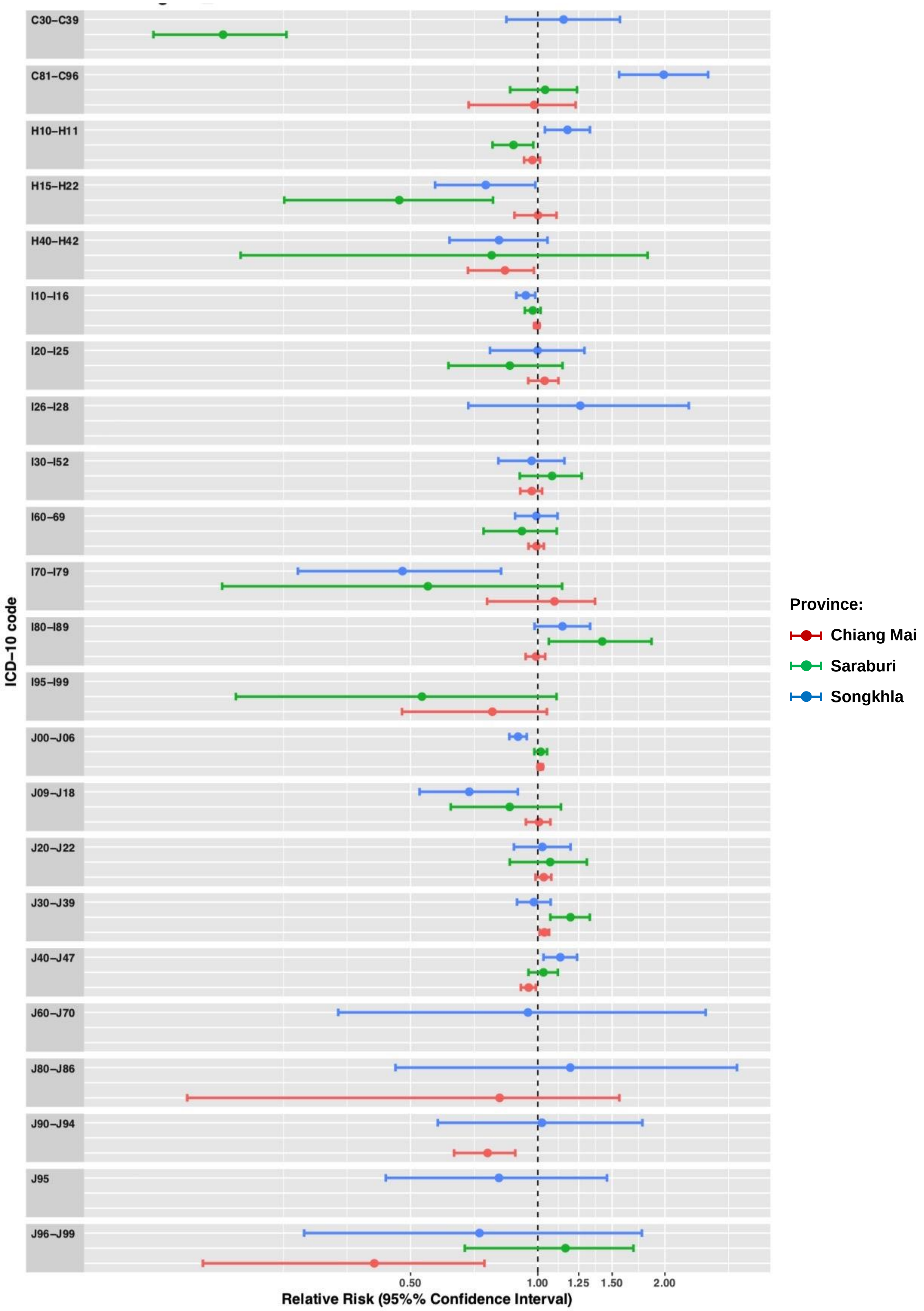
PM2.5: 25-29 Age Group



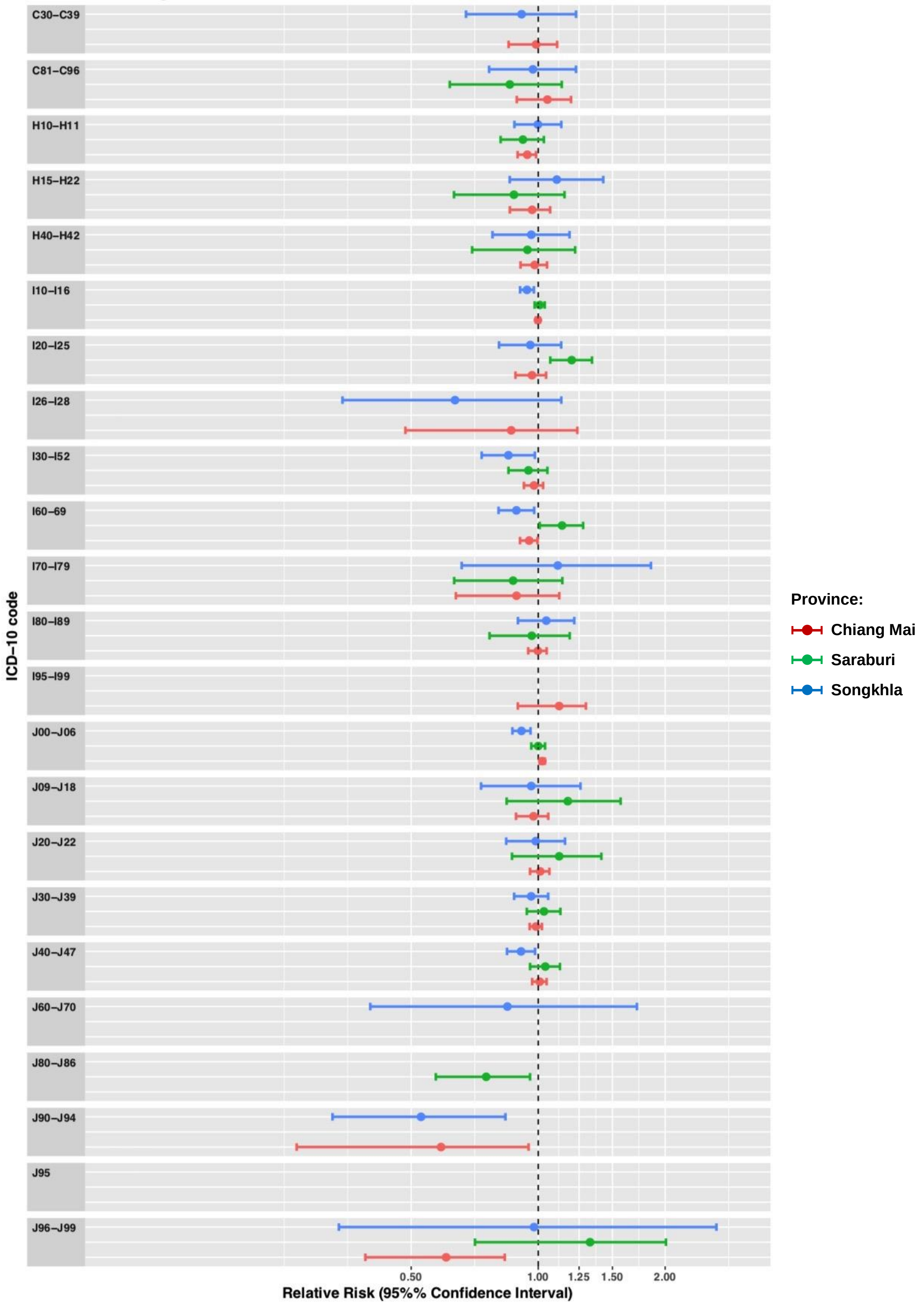
PM2.5: 30-34 Age Group



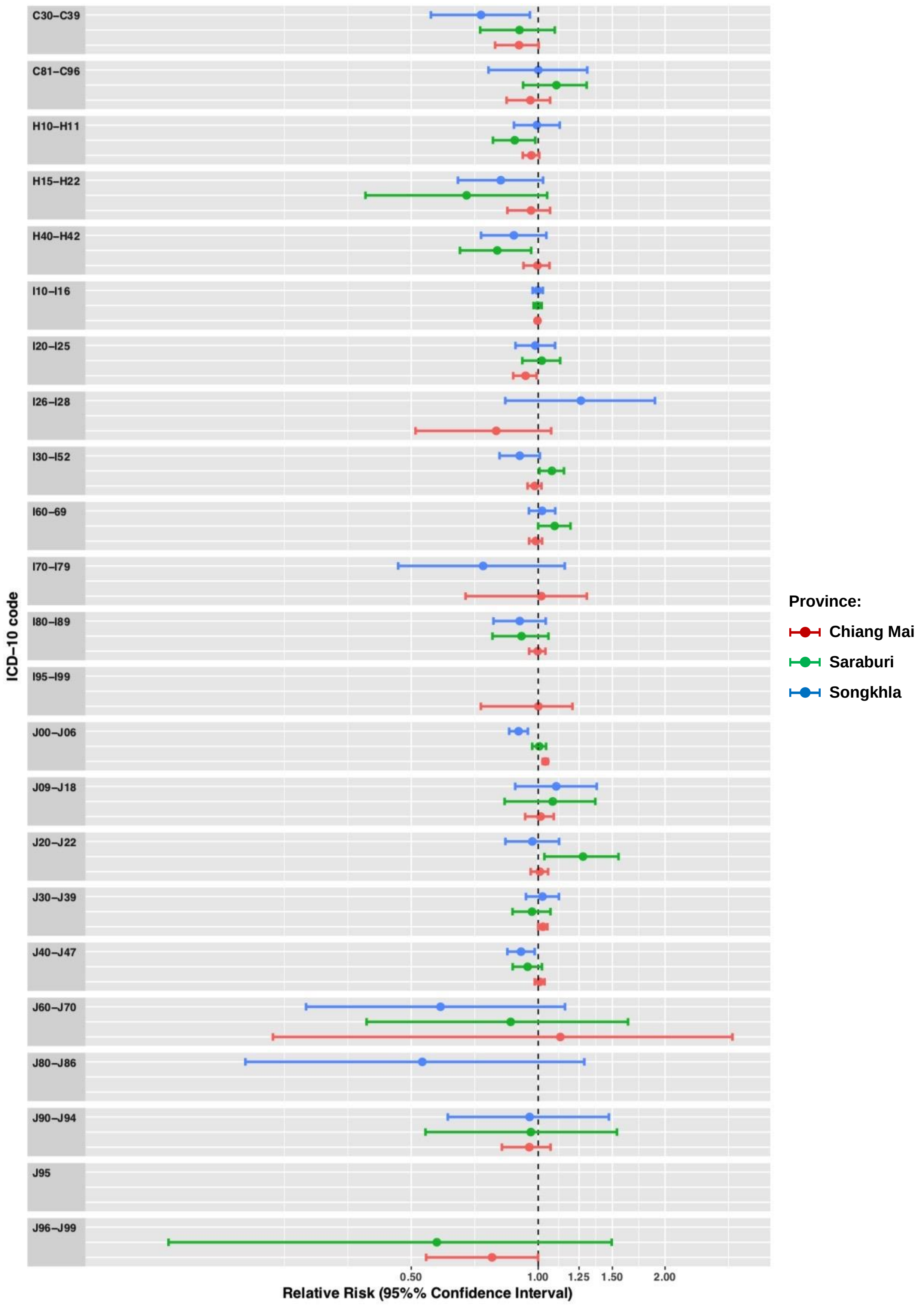
PM2.5: 35-39 Age Group



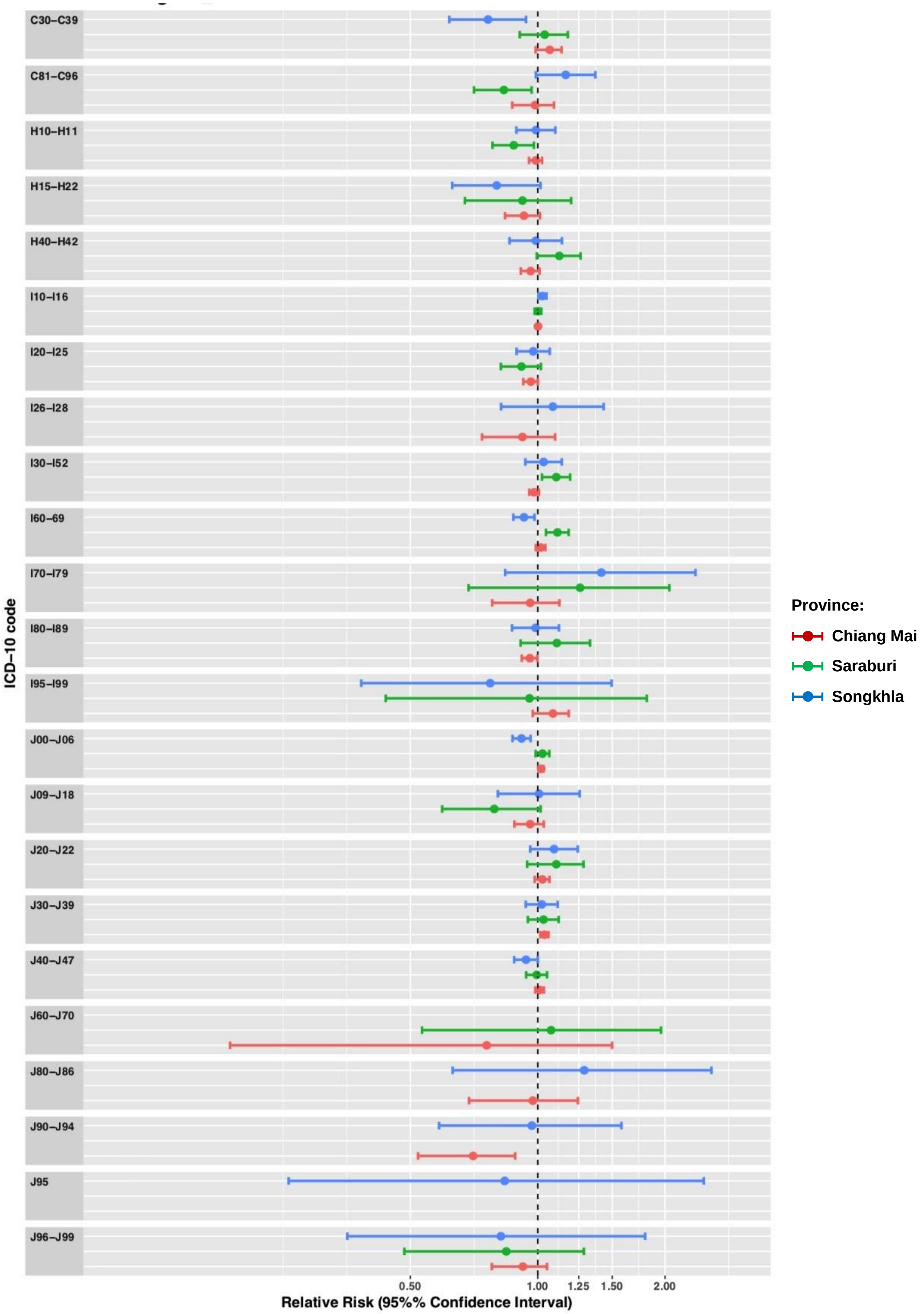
PM2.5: 40-44 Age Group



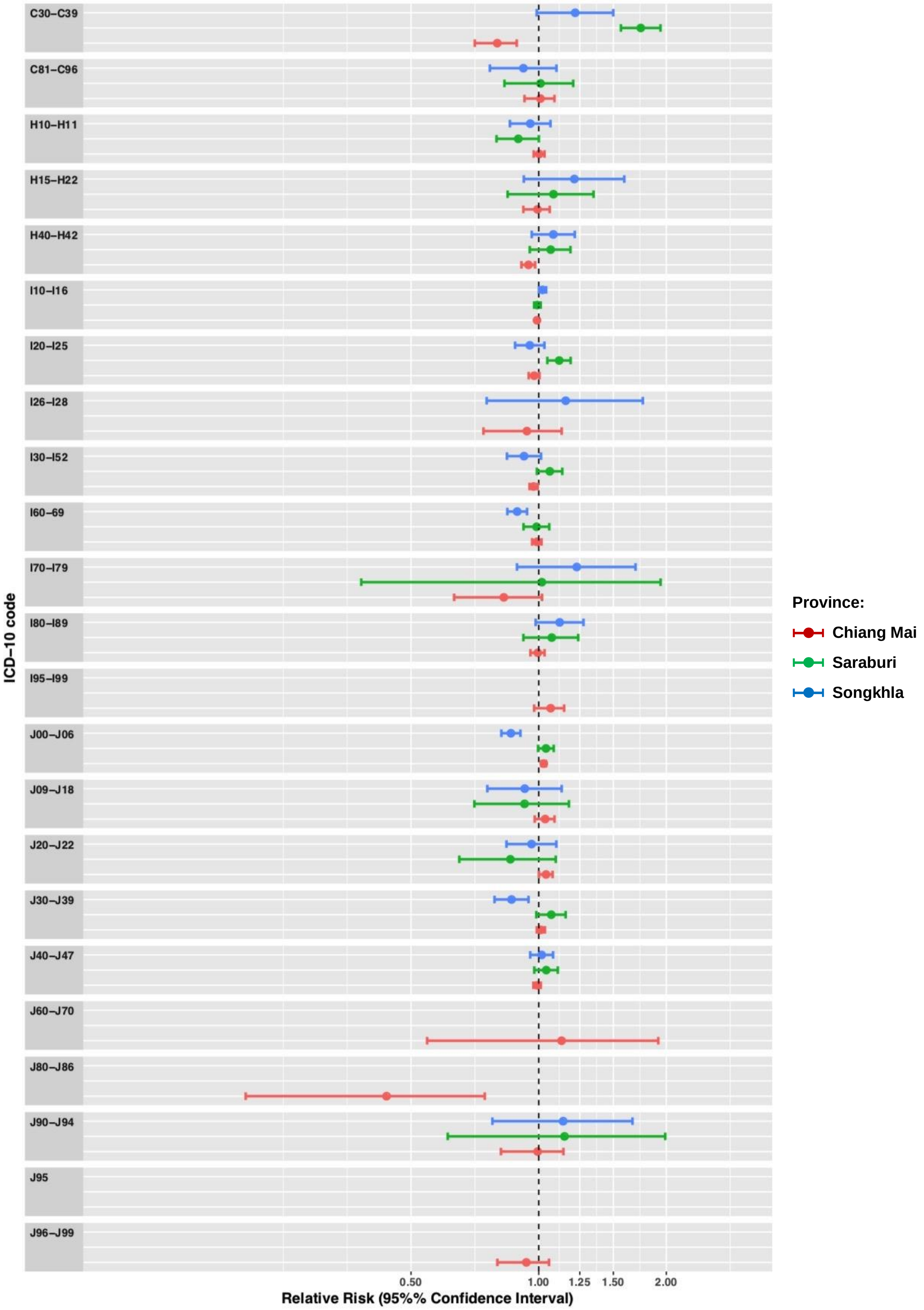
PM2.5: 45-49 Age Group



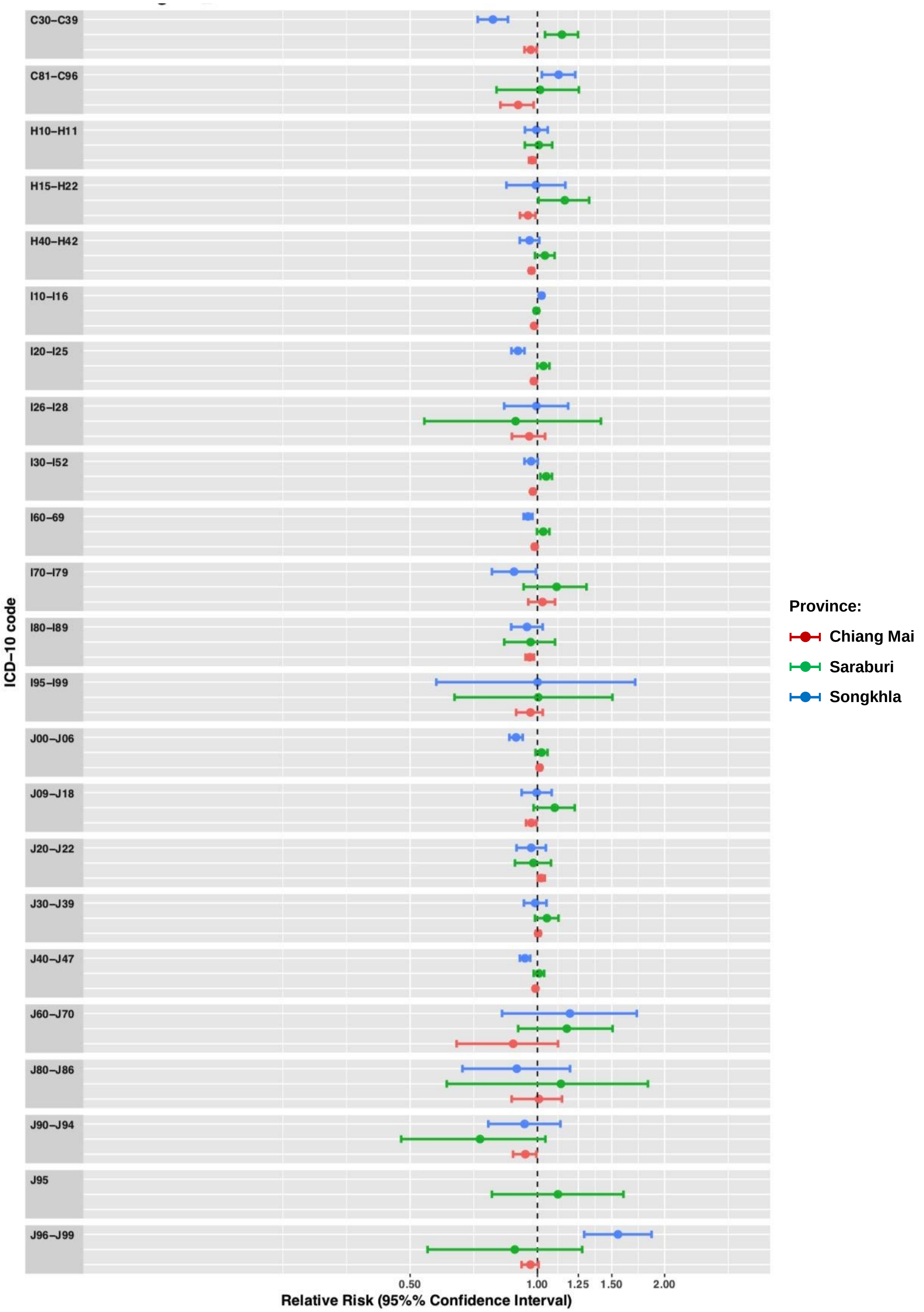
$PM_{2.5}$: 50-54 Age Group



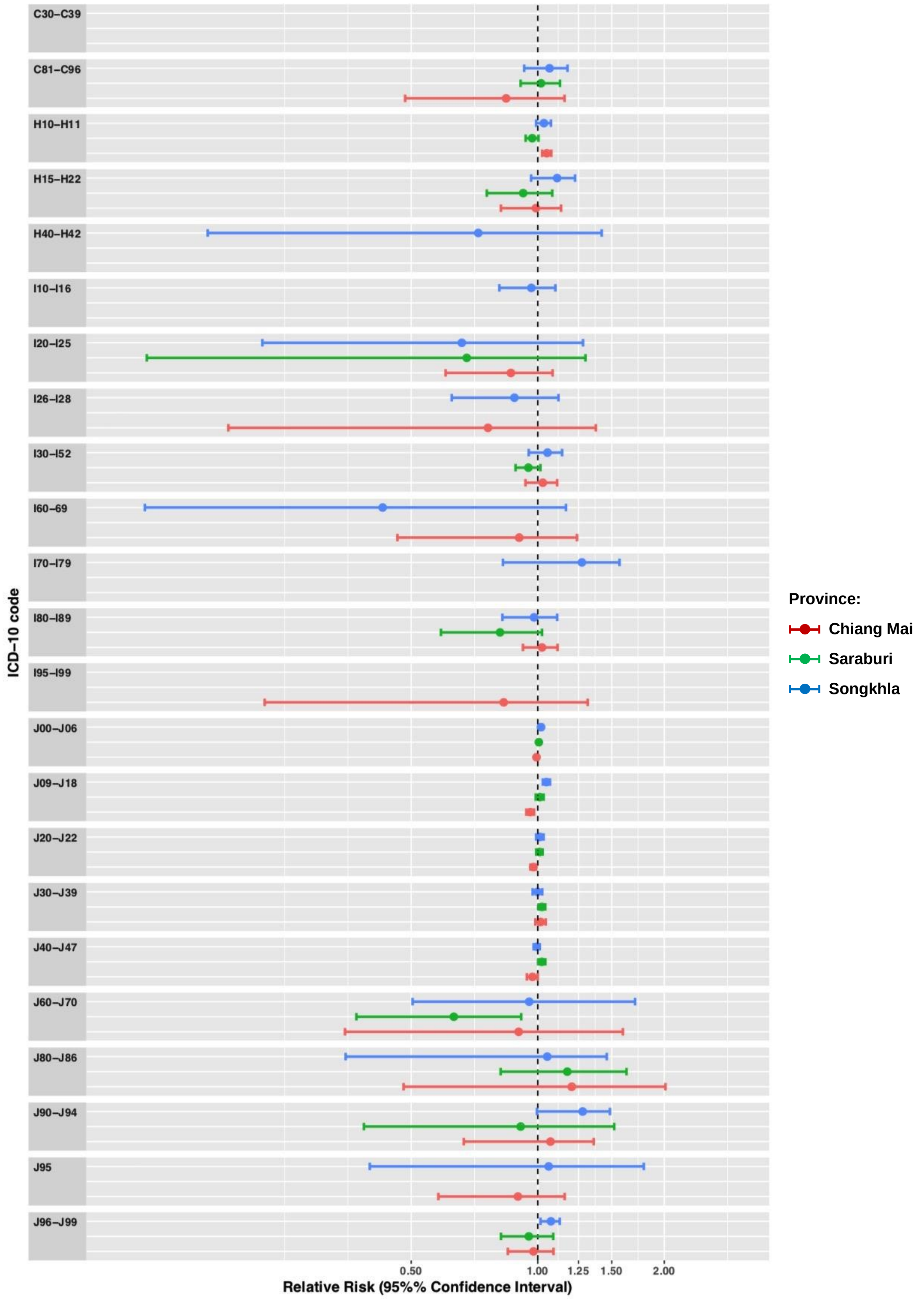
PM2.5: 55-59 Age Group



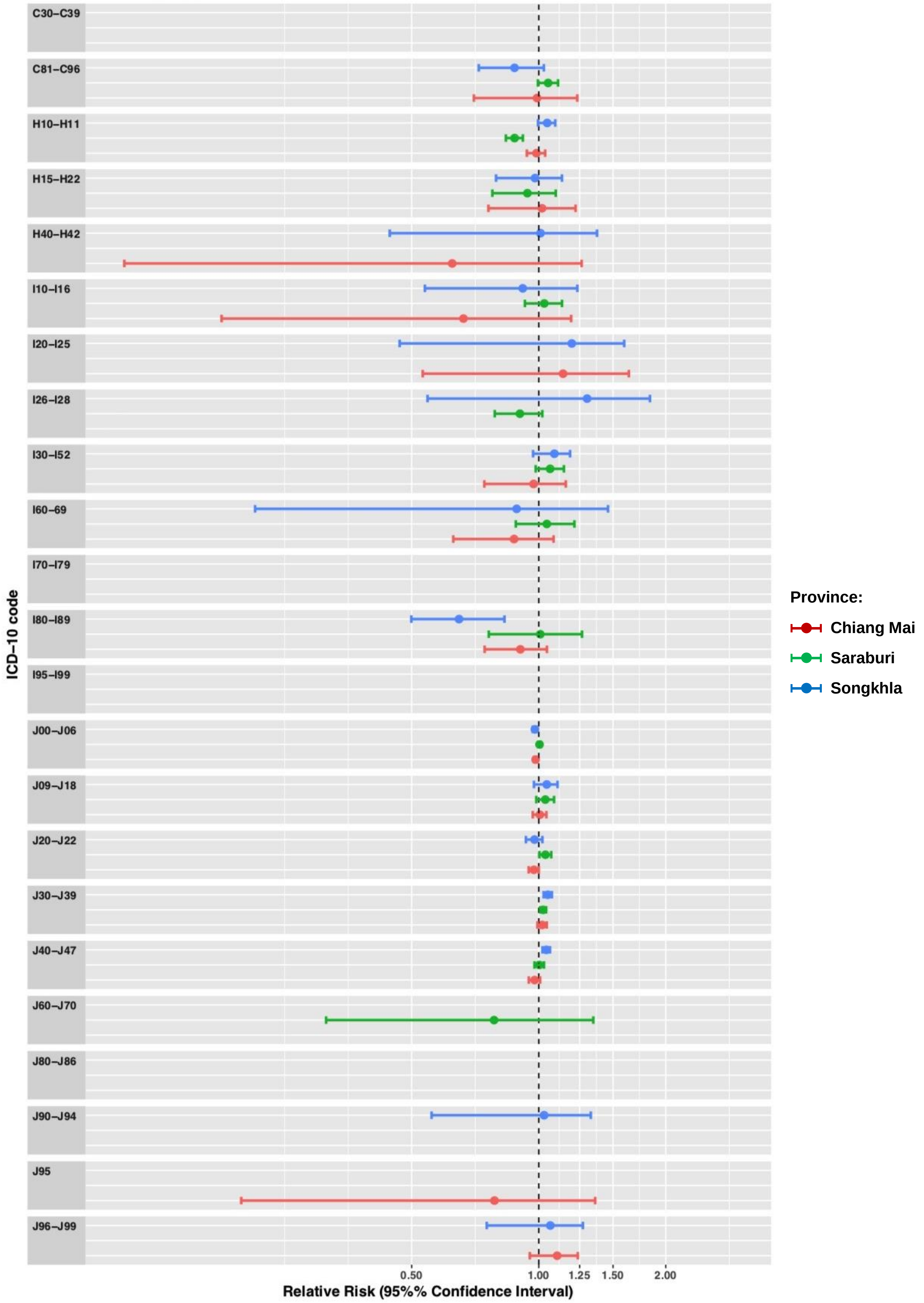
PM2.5: 60+ Age Group



PM_{10}: 0-4 Age Group

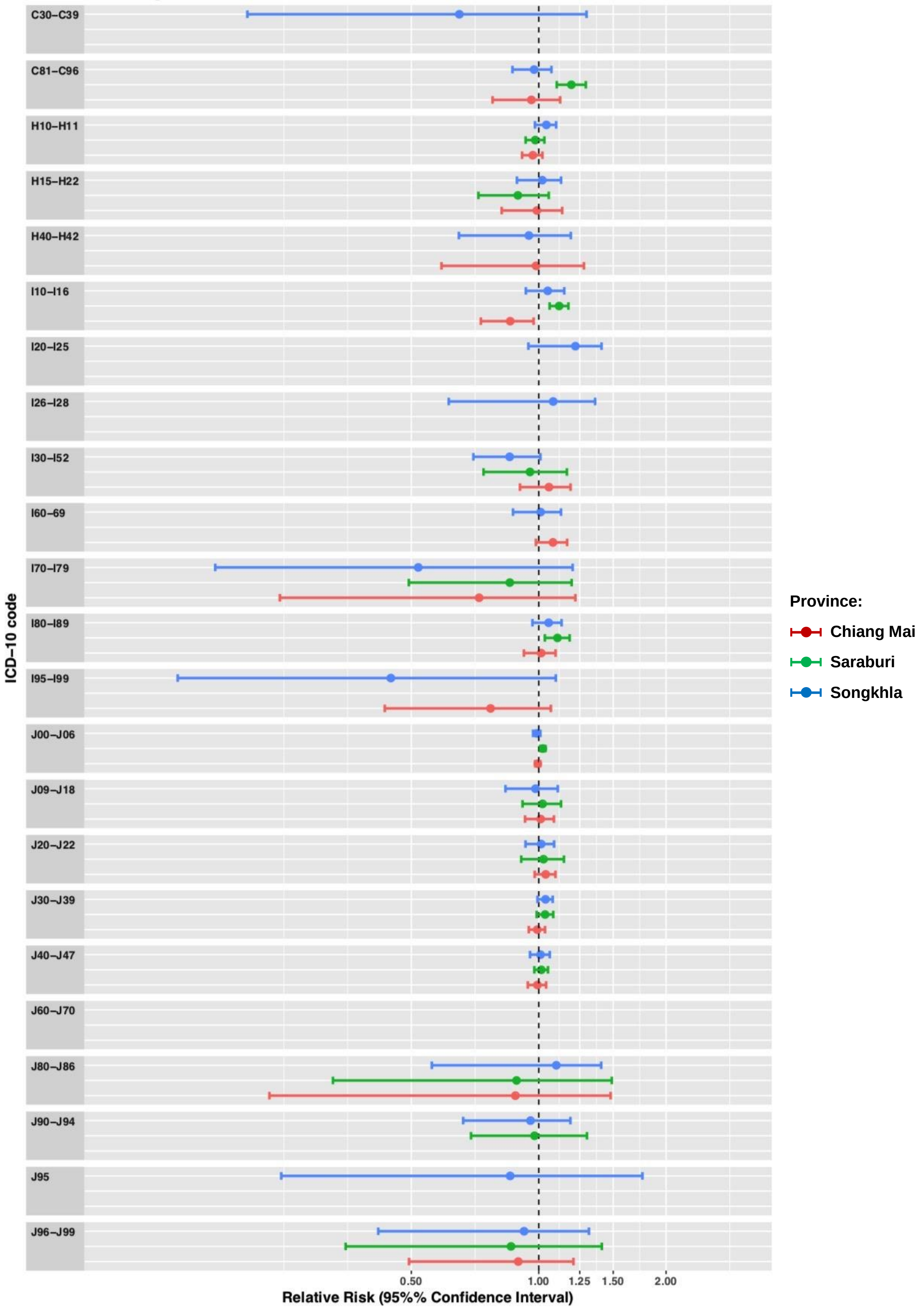


PM10: 5-9 Age Group

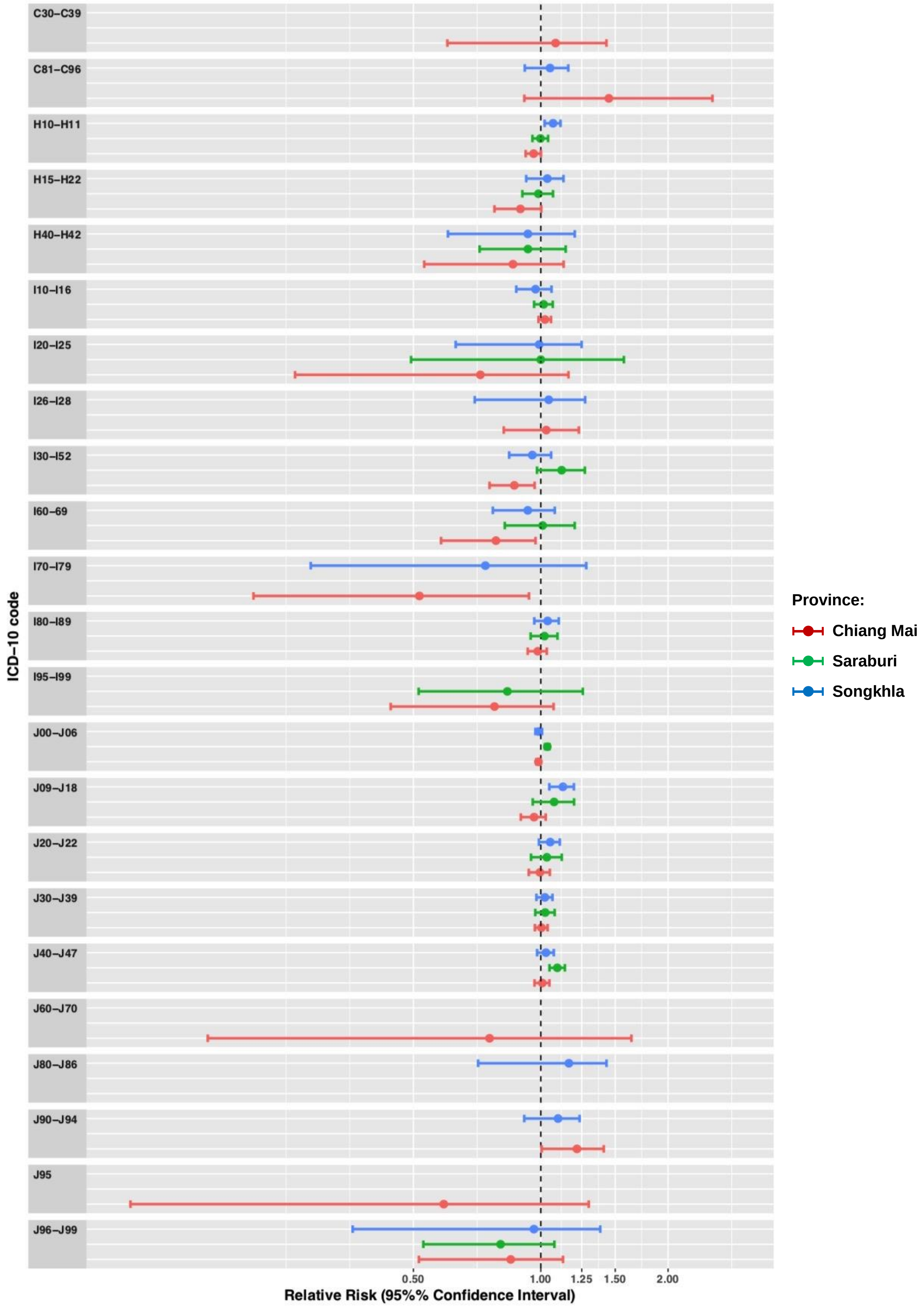


PM_{10}: 10-14 Age Group

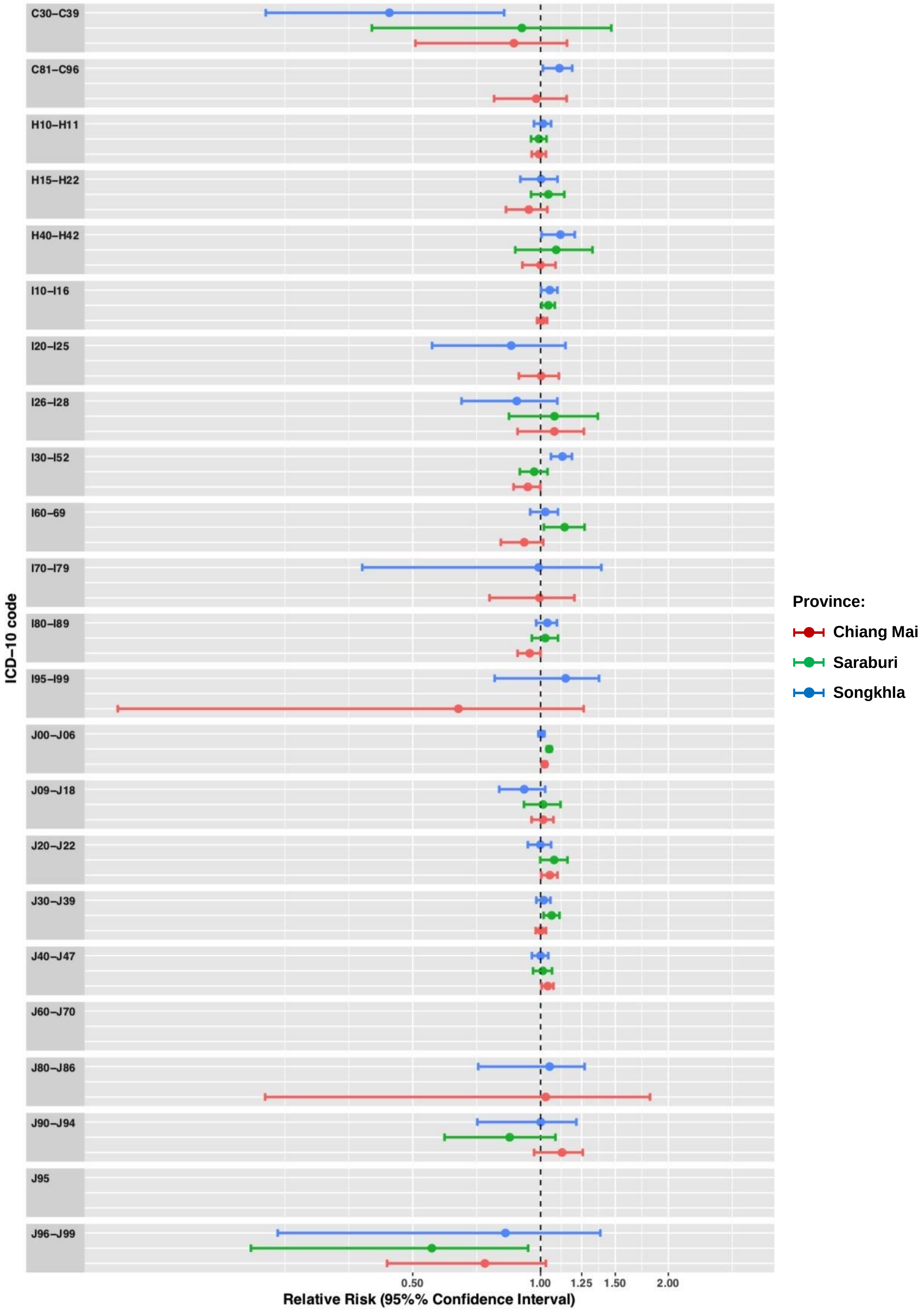
PM_{10}: 15-19 Age Group



PM10: 20-24 Age Group



PM10: 25-29 Age Group

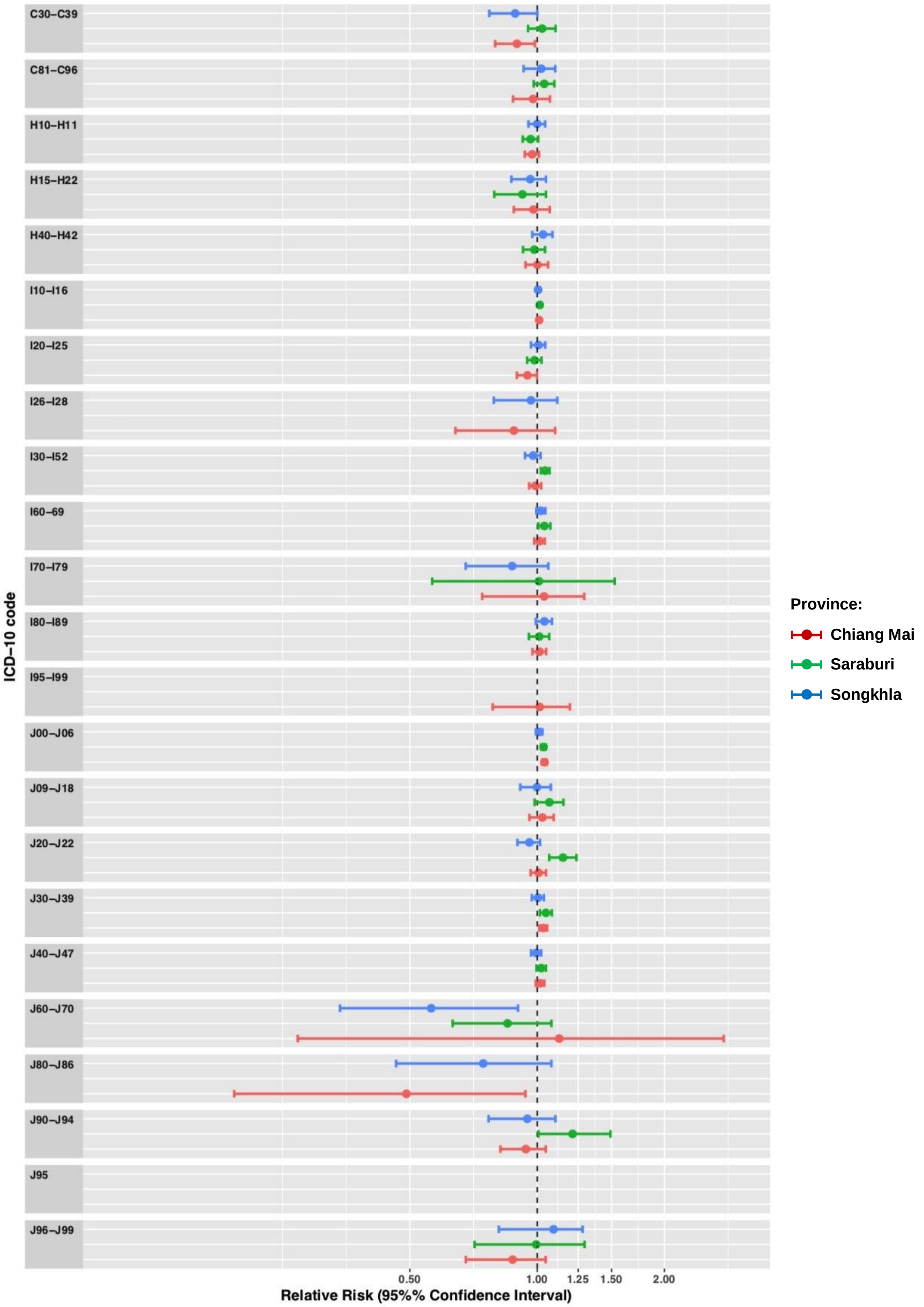


PM$_{10}$: 30-34 Age Group

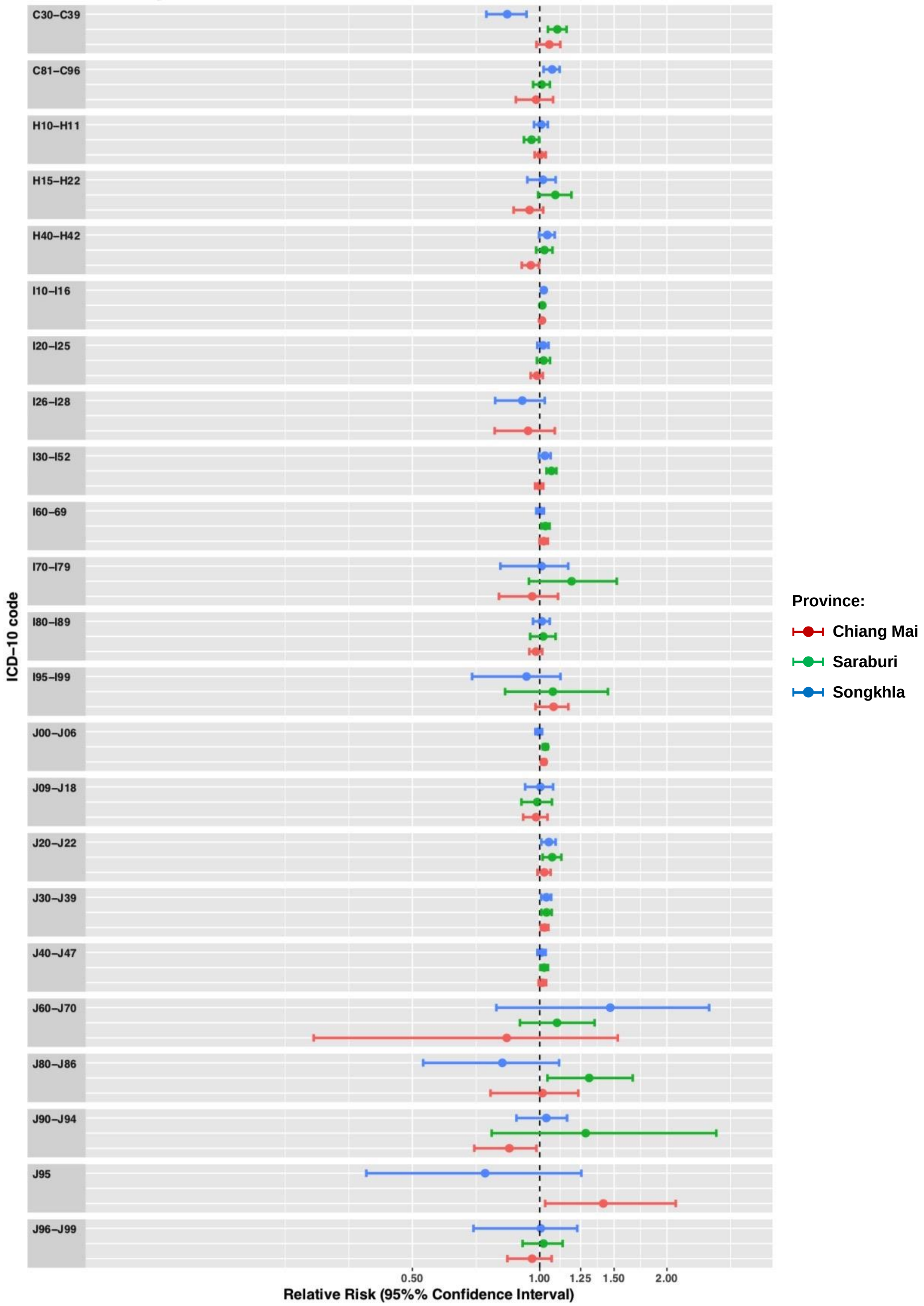
PM_{10}: 35-39 Age Group

PM$_{10}$: 40-44 Age Group

PM10: 45-49 Age Group



PM_{10}: 50-54 Age Group



PM_{10}: 55-59 Age Group

PM10: 60+ Age Group