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Characterizing the spectrum of mortality in a cohort of people exposed to indoor air pollution in Xuanwei, China (1976-2011)

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Rutgers University- New Brunswick

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An abstract of

A thesis submitted to the Faculty of the
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Abstract

Characterizing the spectrum of mortality in a cohort of people exposed to indoor air pollution in Xuanwei, China (1976-2011)

By: Teja Nagaradona

Background: Xuanwei (XW) county in Yunnan Province, China has one of the highest lung cancer rates in the world, particularly among never-smoking women. This has been attributed to the combustion of smoky coal, used for cooking and heating in the household. However, the broader spectrum of cause-specific mortality in this unique population has not been well-characterized, including among those who use smokeless coal, which is perceived as a "safer alternative" coal type among many residents of XW.

Methods: A cohort of 42,220 men and women living in XW were followed from 1976-2011. Two questionnaires, one at baseline (1992) and one at follow-up (2009) of non-deceased respondents, were administered to assess various demographic and lifestyle characteristics, including lifetime coal use. Cause-specific mortality rates through 2011 were calculated in lifetime users of smoky and smokeless coal.

Results: The mortality rate of total cancer was four times higher among lifetime users of smoky coal (578 deaths /100,000 people) relative to lifetime smokeless coal users (138 deaths /100,000 people) in XW (RR=4.01, 95% CI= 3.40-4.80). In contrast, lifetime smokeless coal users had higher mortality rates of CVD (615 deaths /100,000 people) relative to smoky coal users (323 deaths /100,000 people; RR=2.96, 95% CI= 2.70-3.24). Similar rates were observed when stratified by sex. Rates of total COPD (RR= 1.21, 95% CI=1.0-1.31) and lung cancer (RR=17.30, 95% CI=12.58-23.72) were higher among smoky compared to smokeless coal users, whereas pneumonia rates were higher among smokeless coal users (RR=2.29, 95% CI=1.75-2.99).

Conclusion: Evidence from this study suggests that the cause-specific burden of mortality differs in XW based on the use of different coal types. These descriptive observations provide etiologic hypotheses that should be evaluated in future epidemiologic studies of coal use and mortality risk.

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Table of Contents:

Background:

The global prevalence of exposure to household air pollution (HAP) is substantial, as almost 40% of the world's population are exposed to HAP from solid fuel use for indoor cooking and heating. HAP resulting from the use of solid fuels is also an important contributor to the global disease burden, accounting for ~3.8 million deaths in 2013 (~8% of the global mortality burden) (1). Coal is a popular source of fuel for power generation in both China and India, accounting for almost 40% of energy generation in these countries (2). Since many developing countries continue to use solid fuels such as coal, the health effects of HAP are of increasing concern. A cross-sectional study of 168 people conducted in Nepal identified that individuals exposed to HAP had a three-fold higher risk of developing respiratory illness than individuals who used *cleaner* fuels, such as liquefied petroleum gas (3, 4). Similarly, several studies have linked HAP exposure to cardiovascular disease (CVD) incidence and mortality (5-7). It has been identified that particulate matter present in the pollutants of HAP was associated with elevated risk of cardiovascular (CVD) events regardless of smoking status (8). It is important to illustrate that HAP poses a great threat to the health of individuals whom use solid fuels and population-level interventions could help mitigate burden of disease caused by HAP. Although smoking has been a major driver of respiratory illness and cancer, these findings suggest that HAP contributes greatly to risk of respiratory illness and even cardiovascular events.

Xuanwei (XW) County, in Yunnan Province, China, has one of the highest lung cancer mortality rates in the world including among non-smoking women and in men (9). XW is a rural area where residents predominately use coal for indoor cooking and heating. The HAP resulting from the use of these fuels contributes to high levels of specific pollutants, including $PM_{2.5}$, polycyclic aromatic hydrocarbons (PAHs), and gaseous pollutants (10). Interestingly, levels of some pollutants (e.g. SO_2) have been measured to be higher in homes burning anthracite ("smokeless" coal) whereas others (e.g. PAHs) are higher in homes burning bituminous ("smoky") coal, indicating that the health risks associated with each coal type could differ (11, 12).

In a large cohort study in XW, it was previously observed that non-smoking women who were lifetime users of smoky coal had a ~100-fold elevated risk of lung cancer mortality, compared to women who used smokeless coal during their entire life (13). Smoky coal use has also been associated with respiratory diseases (14). In contrast, the health effects of using smokeless coal are largely unknown and many XW residents regard this coal type as a safer alternative to smoky coal.

China is the world's largest coal producer and it is estimated that 75% of China's primary energy is supplied by domestic coal (15). Two prospective cohorts conducted in China have evaluated the risks associated with solid fuel use. The Kadoorie cohort, which included 5 rural areas in China, identified an association between solid fuel use (wood, biomass, coal) and the risk of all-cause and CVD mortality compared to use of clean fuels (natural gas, ethanol, propane) regardless of smoking status (16). An analysis in the Shanghai Women's Health Study (SWHS) cohort found that past use of coal increased risk of all-cause mortality, cancer, ischemic heart disease, and myocardial infarction. The risk of these outcomes increased as duration of use increased (17). A cohort study in Iran observed that individuals who used kerosene or diesel had an increased risk for all-cause and CVD mortality, compared to a decreased risk of CVD and all-cause mortality when using natural gas (18). This study also evaluated Pehen and wood use, but did not find any significant associations with all cause or subtype specific mortality.

In this study, we aimed to leverage data from the cohort study in XW to evaluate the mortality burden among those who are lifetime users of smoky and smokeless coal. This is the first descriptive epidemiology study to evaluate the cause-specific mortality burden in lifetime coal users, stratified by coal type. Based on our descriptive observations, we additionally evaluated the risk of smoky coal on lung cancer mortality and the risk of smokeless coal on CVD mortality using multivariable Cox regression models using the most recent follow-up data from the XW cohort.

Methods:

Study Population and Data Collection

The design of the XW cohort study has been described in detail (13, 19). In brief, the study area was comprised of three communes in which two different coal types were the primary fuel source. Residents of one commune primarily used smoky coal, whereas residents living in the other communes primarily used smokeless coal. A review of administrative records was conducted in 1992 in order to identify all people born between 1917-1951 who lived in the study area. The cohort comprised 42,420 participants (age ranged from 25 to 59 years old at baseline) that were alive as of January 1,1976, including a sub cohort of 20,719 women nearly of whom did not smoke (non-smokers, n=20,680). In 1992, trained interviewers administered a standardized questionnaire directly to the study subjects or their surrogates. The questionnaire assessed lifetime residential history, cooking practice, household fuel and stove use, the average number of rooms and people in each residence, education, smoking history, and cooking practices. Respondents or their proxies were queried on their amount of fuel that was used, the primary fuel source, and the type of cooking apparatus that was used in the main living or cooking area (stove with chimney, portable stove, unvented fire pit, and stove without a chimney) over their entire lifetime. A follow-up questionnaire was administered between 2009-2011 directly to participants (or their proxies) still alive after 1992. The date and cause of death for subjects in the cohort during the follow-up period (January 1, 1976 to December 31, 2011) were obtained from death certificate and hospital records. Cause of death was coded by the Center for Disease Control according to the International Classification of Diseases, 9th revision (ICD-9), including for cancer (ICD-9 140-239, CVD (ICD-9 390-459), ischemic heart disease (410-414), stroke (430-438), respiratory causes (ICD-9 460-519), COPD (490-496), pneumonia (500-508), gastrointestinal diseases (GI) (ICD-9 520-579), and genitourinary diseases (ICD-9 580-629).

Statistical Analysis

To quantify the burden of mortality from multiple cause-specific endpoints in XW (1976-2011), we calculated age-adjusted mortality rates overall and stratified by sex among lifetime users of smoky and smokeless coal. Rates were adjusted to the World Health Organization (WHO) 2000-2025 world standard population within five age groups (24-44, 45-54, 55-64, 65-74, 75+). Average age of death by coal type was also evaluated and age specific mortality rates were calculated. To compare rates between smoky and smokeless coal users, mortality rate ratios and 95% confidence intervals (95% CI) were calculated for each outcome. We also compared the cause-specific mortality rates among women in XW to those in the population-based SWHS(20). For this comparison, analyses were restricted to mortality occurring during 1997-2009 in XW to reflect the follow-up period for the SWHS (1997-2009). We restricted the comparisons to non-smoking women only. Multivariable Cox regression models were constructed to compare mortality hazards for lung cancer (ICD-9 code 162) between smoky and smokeless coal users. Similar models were constructed to compare mortality hazards for CVD (ICD-9 429) between smokeless coal users and smoky coal users. Variables included in the Cox models were type of coal, if stove was changed at any time (i.e., fire pit to stove with chimney), and formal education. Average number of waking hours, duration of cooking, average number of rooms, and the average number of people living in the household during the subjects lifetime were also considered in the model based on directed acylical graphs (DAG) for both coal types (see Supplemental Figures 3&4). All models were stratified by age group (0-47, 47-54, 54-60, 60-65, 65-70, >75). To evaluate potential differences in outcome mortality during the retrospective and prospective periods of the study, Cox models were run restricting to the periods of 1976-1992 (retrospective follow-up) and 1992-2011 (prospective follow-up). Analyses were conducted using the PROC STDRATE procedure and PROC PHREG in Statistical Analysis Software (SAS) version 9.4 (Cary, NC).

Results:

Distribution of Mortality in (1976-2011)

The proportion of cause-specific mortality among men and women in XW is shown in Figure 1A. Mortality among men and women overall in XW was driven by cancer (32%) and CVD (19%) (Figure 1D). Among lifetime smoky coal users, the causes of mortality were driven by cancer (41%), among which nearly 90% were due to lung cancer (Figure 1B & E). In contrast among lifetime smokeless coal users, CVD accounted for the majority of deaths (32%) followed by respiratory diseases (21%), as well as other (26%) causes of mortality, which included a variety of other mortality outcomes not examined separately in our analysis. There was a much smaller percentage of deaths due to cancer (7%) among lifetime smokeless coal users (Figure 1C). In addition, the spectrum of cancer mortality among lifetime smokeless coal users was not predominated by lung cancer but rather a combination of a variety of sites (Figure 1F). Distributions by both sex and coal type are provided in Figure 2 with similar proportions to Figure 1.

Rates of Mortality in (1976-2011)

Table 1 shows the age adjusted rates of mortality for all evaluated mortality outcomes among smoky and smokeless coal users. Among lifetime smoky coal users compared to lifetime smokeless coal users, the highest rates were observed for total cancer (577.9 deaths/ 100,000 deaths, RR=4.01(95% CI 3.98-4.05), lung cancer (500.9 deaths/100,000 person-years, RR=17.3 (95% CI 17.0-17.6), esophageal cancer (3.4 deaths/100,000 person years, RR= 2.73 (95% CI 2.70-2.75), and brain cancer (7.5 deaths/100,000 person-years, RR= 4.37 (95% CI 4.32-4.40). Among lifetime smokeless coal users compared with smoky coal users, the highest rates of mortality were for CVD (208.6 deaths/ 100,000 person years, RR=2.94 (95% CI 2.77-3.33), respiratory causes (323.2 deaths/100,000 person-years, RR=1.14 (95% CI 1.11-1.25), gastrointestinal causes (53 deaths/ 100,000 person-years, RR=4.17 (95% CI 3.33-5.00), and genitourinary causes (15.3 deaths/ 100,000 person-years, RR=4.76 (95% CI 4.01-5.02).

Table 2 highlights the overall age-adjusted mortality rates among male and females stratified by coal type. The male and female rates for overall and cause specific mortality in a given coal type are similar. Overall cancer mortality was 3.3 (95% CI 2.7-4.1) times higher in male smoky coal users than in smokeless coal users. Female smoky coal users had 5.4 (95% CI 4.0-7.2) times higher mortality overall than smokeless coal users. Male smoky coal users had a 14.4 (95% CI 9.62-21.69) times greater rate of mortality from lung cancer compared to smokeless coal users. Women had a 24.0 (95% CI 14.6-39.6) times greater rate of death from lung cancer compared to smokeless coal users. Among smokeless coal users, liver cancer and stomach cancer among men was significantly higher compared to smoky coal users. Similarly, CVD, ischemic heart disease, and stroke were all significantly higher among both male and female smokeless coal users ($P<0.05$).

Shanghai Comparison

We compared overall and cause-specific mortality rates among women in our study to women in Shanghai. Overall mortality was 2.4 (95% CI 2.3-2.5) times higher in XW women compared to Shanghai women without stratification of coal type. Among women who used smoky coal in XW, overall mortality was 3.1 (95% CI 2.9-3.4) times higher in smoky coal users and 3.8 (95% CI 3.4-4.4) times higher among smokeless coal users compared to Shanghai women (Figure 3). Lung cancer mortality was 14.2 (95% CI 12.1-16.6) times higher in smoky coal users. Similarly, CVD mortality was 5.2 (95% CI 4.3-6.4) times higher, stroke was 3.9 (95% CI 2.7-5.5) times higher, and ischemic heart disease mortality was 3.1 (1.8-5.2) times higher in XW women who used smokeless coal compared to Shanghai women.

Cox results

Table 3 shows associations between lifetime smoky coal and lung cancer mortality risk compared to smokeless coal users, as well as the risk of CVD among lifetime smokeless coal compared to smoky coal users. During the 1976-2011 time period, individuals who used smoky coal had a lung cancer mortality risk of 15.87 (95% CI=11.95-21.10) compared to smokeless coal users. Smokeless coal users were about 2.5 (95% CI 2.28-2.74) times more likely to die from CVD than smoky coal users during the time period 1976-2011. When evaluating these associations within the stratified time periods (1976-1992 and 1992-2011), we observed a significantly increased risk of lung cancer mortality among smoky coal users and a significantly increased risk of mortality from CVD among smokeless coal users, each in relation to the other coal type, respectively.

Supplemental Analysis:

Supplemental Table 1 highlights the average age of mortality. Overall, individuals who used smoky coal and had lung cancer died earlier (59.1 years) than individuals who used smokeless coal and had lung cancer (63.8). When looking at the age of mortality across coal types, individuals who used smoky coal died ealier than individuals who used smokeless coal. Supplemental Figure 1 highlights the age specific mortality rates across the two coal types. The mortality rates of all of the outcomes remained fairly constant with age as predicted. Mortality rates decresed in indviduals with lung cancer and overall cancer in both coal types. Whereas mortality rates increased in both coal types among individuals with COPD. Pnuemonia provided the most drastic finding with mortality rates sharply dropping in the older age group (64-75+). Similar results were seen in Supplemental Figure 2 when the age specific mortality rates were stratified by both sex and coal type. Similar observations were see when stratified by coal type and sex, with similar patters in lung cancer, overall cancer, COPD and pneumonia.

Discussion and Future Directions:

This descriptive analysis found that rates of lung cancer mortality among both men and women in XW continue to be substantially higher among smoky coal users compared to smokeless coal users. Similarly, mortality rates of COPD were higher among smoky coal users compared to smokeless coal users for both men and women. In contrast, a striking finding in our study is that individuals exposed to smokeless coal had higher rates of total CVD, stroke, ischemic heart disease, and gastrointestinal mortality compared to smoky coal users, irrespective of sex. It is important to highlight the patterns of mortality. The proportion of cause-specific mortality among smoky versus smokeless coal were different. In addition, there were significant differences in mortality rates for different end points for lifetime use of smoky coal versus smokless coal. Finally, when comparing the endpoints to an external population, the mortality rates in XW are higher than rates in Shanghai.

In order to gain a more contextual understanding of mortality burden in XW, we compared the rates of mortality for several outcomes to an external Shanghai population consisting of predominately non-smoking women. We found that the rates of all outcomes evaluated in this study were higher in XW. Smokeless coal was associated with CVD, stroke, ischemic heart disease, COPD, gastrointestinal, and genitourinary mortality, where as smoky coal exposure was associated with mortality from lung cancer and pneumonia for the time period we compared with the Shanghai population. It is important to note that our analysis comparing rates in XW to Shanghai only focused on women since the majority of men in XW and in Shanghai smoked. Therefore, the interpretation of the mortality rates would have been more complex among men particularly for smoking related diseases. To follow-up on our descriptive observations, which suggested high mortality rates of lung cancer among lifetime smoky coal users and high rates of CVD mortality among lifetime smokeless coal users, we further evaluated these associations using a multivariable modeling framework that considered adjustment for several demographic and lifestyle characteristics that could be confounders. We found that lung cancer and CVD mortality were consistently associated with smoky coal and smokeless coal use, respectively, and that these associations were observed in both men and women. Among smoky coal users, lung cancer risk was particularly high in women, most likely due to extended time cooking relative to men.

Coal exposures are well established to be associated with lung cancer (21). In addition, the Kadoorie cohort observed hazardous effects of burning solid fuels indoors and increased mortality risks for cardiovascular outcomes (16). The use of cooking coal indoors was also associated with higher all-cause and cause specific mortality from cancer, ischemic heart diseases, and myocardial infarction in the SWHS cohort, although in this study the type of coal being used was not examined separately (17). This study highlights the mortality risks from coal exposure and further details the effects of household air pollution on health and mortality in the Chinese population.

This study is the first to our knowledge to identify the spectrum of disease burden in XW due to coal exposure. Many previous studies have elucidated the burden of lung cancer mortality because of the immense HAP that is present in this region. The burden of lung cancer in XW has been influenced by the proximity of the villages to the coal (22). Although proximity to coal communes in XW may play a role in lung cancer burden, the constituents of the coal are the more likely cause of lung cancer and other diseases. Therefore, it is plausible that constituents from both smoky coal and smokeless coal like PAHs are responsible for the various disease burdens that plague XW County. Current literature has identified that the mortality patterns of lung cancer have not changed in XW (23). This present study suggests that this still holds true as the lung cancer burden was staggering among smoky coal users. Our study adds to this conclusion as it suggested that other diseases may be associated with coal use in this region and provided data on the total disease burden in XW.

One limitation of this study was that the Shanghai population was evaluated in a more urban population setting. The effects of vehicular air pollution, as well as other outdoor air pollutants that entered homes, and differences in some lifestyle characteristics may have contributed to mortality rates. A second limitation of this study is that exposure data was self-reported. This could lead to recall bias, however since most of the people who lived in these areas lived there for their lifetime, they are more likely to recall the type of coal they used. Finally, due to the descriptive nature of the study, the conclusions drawn only provide an overview of disease burden in the population, however, this will lead to future studies that will evaluate various associations with coal use and cause-specific mortality. It is also important to consider that the possibility of high lung cancer mortality due to smoky coal may artificially lower the mortality rates of other diseases.

In conclusion, this study was able to highlight the spectrum of disease that was associated with both smoky and smokeless coal use. This study was also able to highlight the major differences in rates of mortality in XW, as well as in relation to a comparison group (Shanghai). Future studies are needed in order to elucidate the effects of possible stove improvements as well focus on the effects of coal use and the outcomes highlighted in a model based framework while adjusting for confounders. This will be conducted by linking data on individual HAP consitiuents to the cohort in order to evaluate cause specific mortality risks.

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Tables and Figures:

Table 1: Overall Age Adjusted Mortality Rates by Type of Coal Use in Xuanwei, 1976-2011

Category:	Smoky-N	Overall Age-Adjusted Rate[1]	Smokeless-N	Overall Age-Adjusted Rate	Smoky vs. Smokeless Rate Ratio
Overall	11520	1543.7	2886	2060.4	0.70(0.71-0.82)
Cancer	4707	577.9	197	138.3	4.01(3.42-4.83)
Lung Cancer	4144	500.9	49	28.7	17.3(12.62-23.71)
Stomach Cancer	84	10.3	31	23.8	0.40(0.31-0.54)
Liver Cancer	133	15.5	52	35.5	0.40(0.21-0.62)
Breast Cancer	19	2.4	7	4.5	NA*
Esophageal Cancer	29	3.4	2	1.3	2.73(0.60-12.4)
Nasopharyngeal Cancer	15	2.0	5	3.4	NA
Bone Cancer	43	5.3	0	0.0	NA
Brain Cancer	61	7.5	2	1.8	4.37(1.1-17.9
Colorectal Cancer	35	4.0	10	6.5	NA
Pancreatic Cancer	10	1.2	2	1.4	0.97(0.2-4.8)
Cervical Cancer	5	0.8	0	0.0	NA
Ovarian Cancer	2	0.4	0	0.0	NA
Bladder Cancer	8	1.0	5	3.0	NA
CVD	1530	208.6	926	614.5	0.34(0.33-0.37)
Ischemic Heart Disease	161	22.7	77	53.1	0.43(0.31-0.58)
Stroke	650	90.3	227	153.7	0.59(0.51-0.67)
Respiratory Cause	2370	323.2	618	368.6	0.88(0.81-0.97)
Pneumonia	188	27.6	109	63.2	0.43(0.33-0.57)
COPD	1752	236.5	330	199.5	1.2(1.0-1.31)
Gastrointestinal cause	396	53.0	307	222.8	0.24(0.20-0.29)
Genitourinary cause	113	15.3	90	72.0	0.21(0.15-0.29)

*NA- Rate Ratios could not be calculated due to an insufficient number of cases either overall or in certain age groups.

Table 2: Overall Age-Adjusted Mortality Rates among Male and Female Smoky Coal and Smokeless Coal Users

Category:	**Male Smoky- N**	**Overall Age-Adjusted Rate**	**Female Smoky- N**	**Overall Age-Adjusted Rate**	**Male Smokeless-N**	**Overall Age-Adjusted**	**Female Smokeless-N**	**Overall Age-Adjusted Rate**	**Male Smoky vs Male Smokeless Rate Ratio**	**Female Smoky Vs. Female Smokeless Rate Ratio**
Overall	6324	1599.4	5196	1478.4	1718	2757.0	1168	1854.7	0.72(0.68-0.77)	0.79(0.77-0.80)
Cancer	2549	588.9	2158	564.1	133	288.0	64	99.5	3.33(2.68-4.13)	5.40(4.0-7.22)
Lung Cancer	2237	517.9	1907	493.4	32	35.2	17	20.7	14.44(9.62-21.69)	24.04(14.60-39.58)
Stomach Cancer	52	11.4	32	9.0	22	29.3	9	16.8	0.38(0.21-0.68)	0.44(0.18-1.06)
Liver Cancer	85	18.4	49	12.6	40	49.8	12	18.0	0.34(0.22-0.54)	0.72(0.37-1.41)
Breast Cancer	2	0.4	17	4.7	0	0.0	7	10.2	NA	NA
Esophageal Cancer	17	3.5	12	3.3	2	2.4	0	0.0	NA	NA
Nasopharyngeal Cancer	5	1.3	10	2.8	2	1.7	3	5.5	NA	NA
Bone Cancer	26	5.1	16	4.3	0	0.0	0	0.0	NA	NA
Brain Cancer	30	7.0	31	7.9	1	1.6	1	2.0	4.26(0.58-31.37)	0.23(0.03-1.70)
Colorectal Cancer	22	4.6	13	3.2	8	8.6	2	4.0	NA	NA
Pancreatic Cancer	4	1.0	4	1.0	2	2.4	0	0.0	NA	NA
Cervical Cancer	0	0.0	5	1.6	0	0.0	0	0.0	NA	NA
Ovarian Cancer	0	0.0	2	0.8	0	0.0	0	0.0	NA	NA

Bladder Cancer	6	1.3	2	0.6	4	4.6	0	0.0	NA	NA
CVD	838	210.6	692	204.7	544	642.2	382	581.1	0.33(0.29-0.37)	0.35(0.30-0.40)
Ischemic Heart Disease	102	26.2	59	18.5	43	52.2	39	63.2	0.50(0.33-0.89)	0.29(0.19-0.46)
Stroke	406	102.8	244	74.8	138	163.6	86	135.4	0.63(0.51-0.77)	0.55(0.42-0.74)
Respiratory Cause	1242	315.7	1128	331.0	343	376.8	274	356.1	0.83(0.73-0.96)	0.93(0.81-1.10)
Pneumonia	107	28.6	81	26.4	62	64.4	47	61.5	0.44(0.31-0.63)	0.43(0.28-0.65)
COPD	917	230.1	835	243.7	189	212.2	139	181.4	1.08(0.9-1.29)	1.34(1.11-1.62)
Gastrointestinal cause	216	56.5	180	49.3	188	255.8	119	184.1	0.23(0.18-0.30)	0.27(0.21-0.36)
Genitourinary cause	76	19.6	37	10.2	58	89.0	32	53.3	0.22(0.15-0.30)	0.20(0.11-0.34)

*NA- Rate Ratios could not be calculated due to an insufficient number of cases either overall or in certain age groups.

Table 3: Hazard of Mortality based on Coal Type by Sex

Smoky Coal			Smokeless Coal		
1976-2011	**Lung Cancer HR**	**95% CI**	**1976-2011**	**CVD HR**	**95% CI**
Overall	15.87	11.95-21.10	**Overall**	2.50	2.28-2.74
Male Model (Controlling for Smoking)	13.45	9.45-19.16	**Male Model (Controlling for Smoking)**	2.75	2.43-3.12
Women Model(Controlling for Smoking)	20.18	12.51-35.58	**Women Model(Controlling for Smoking)**	2.27	1.97-2.61
Women Non-Smoking	20.18	12.50-32.57	**Women Non-Smoking**	2.26	1.97-2.61
1976-1992	**Lung Cancer HR**	**95% CI**	**1976-1992**	**CVD HR**	**95% CI**
Overall	30.20	17.80-51.30	**Overall**	2.19	1.92-2.50
Male Model (Controlling for Smoking)	22.63	12.09-42.38	**Male Model (Controlling for Smoking)**	2.44	2.04-2.93
Women Model(Controlling for Smoking)	48.39	18.09-129.43	**Women Model(Controlling for Smoking)**	1.97	1.62-2.40
Women Non-Smoking	48.43	18.11-129.55	**Women Non-Smoking**	1.96	1.61-2.40
1992-2011	**Lung Cancer HR**	**95% CI**	**1992-2011**	**CVD HR**	**95% CI**
Overall	10.04	7.29-13.83	**Overall**	2.76	2.43-3.13
Male Model (Controlling for Smoking)	9.68	6.37-14.71	**Male Model (Controlling for Smoking)**	2.87	2.44-3.40
Women Model(Controlling for Smoking)	10.38	6.31-17.06	**Women Model(Controlling for Smoking)**	2.62	2.16-3.20
Women Non-Smoking	10.37	6.31-17.05	**Women Non-Smoking**	2.64	2.17-3.21

Figure 1: Proportion of Cause-Specific Mortality by Coal Type

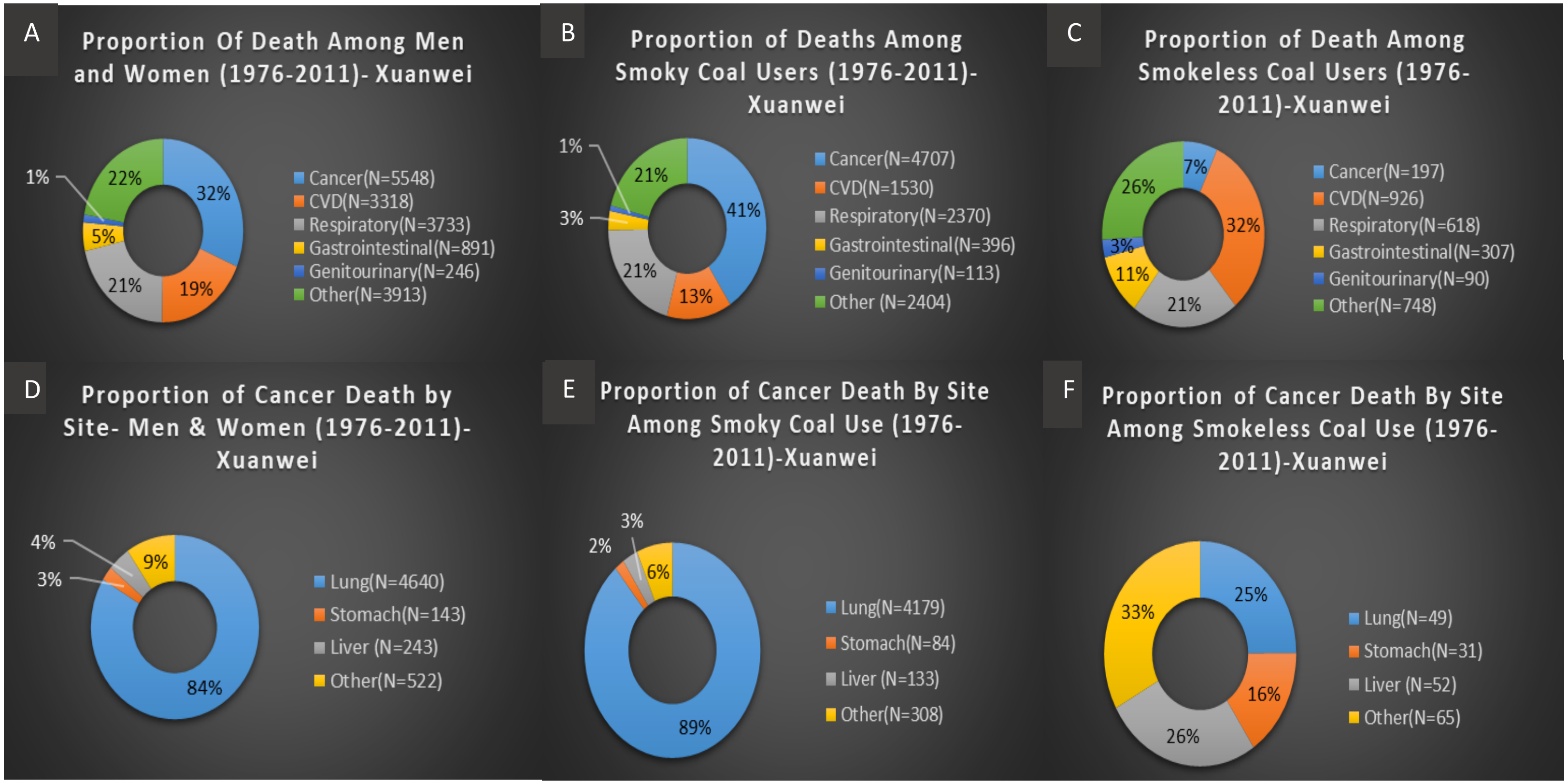


Figure 1A-F. Proportion of mortality among men and women stratified by coal use and cancer site. (A), overall proportion of death, (B), proportion of mortality among men and women stratified by smoky coal type. (C), proportion of mortality among men and women stratified by smokeless coal type. (D-F), proportion of mortality by cancer site overall and stratified by coal type

Figure 2: Proportion of Cause-Specific Mortality by Coal Type and Sex

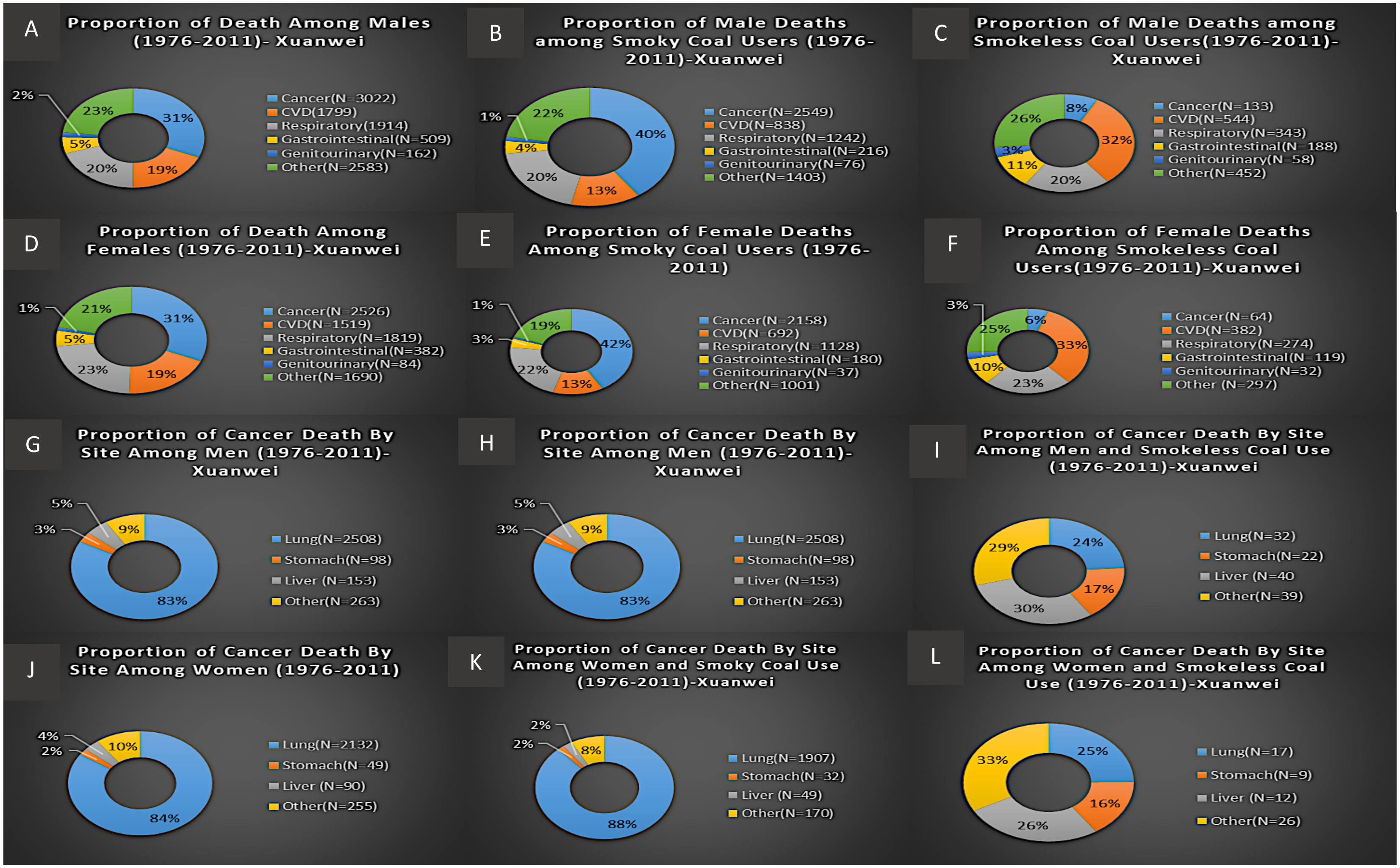


Figure 2. Proportion of mortality stratified by coal type and sex. (A-C), proportion of mortality of males overall and stratified by coal type. (D-F) proportion of mortality of women overall and stratified by coal type. (G-L) proportion of mortality by cancer site stratified by men and women, as well as coal type.

Figure 3:

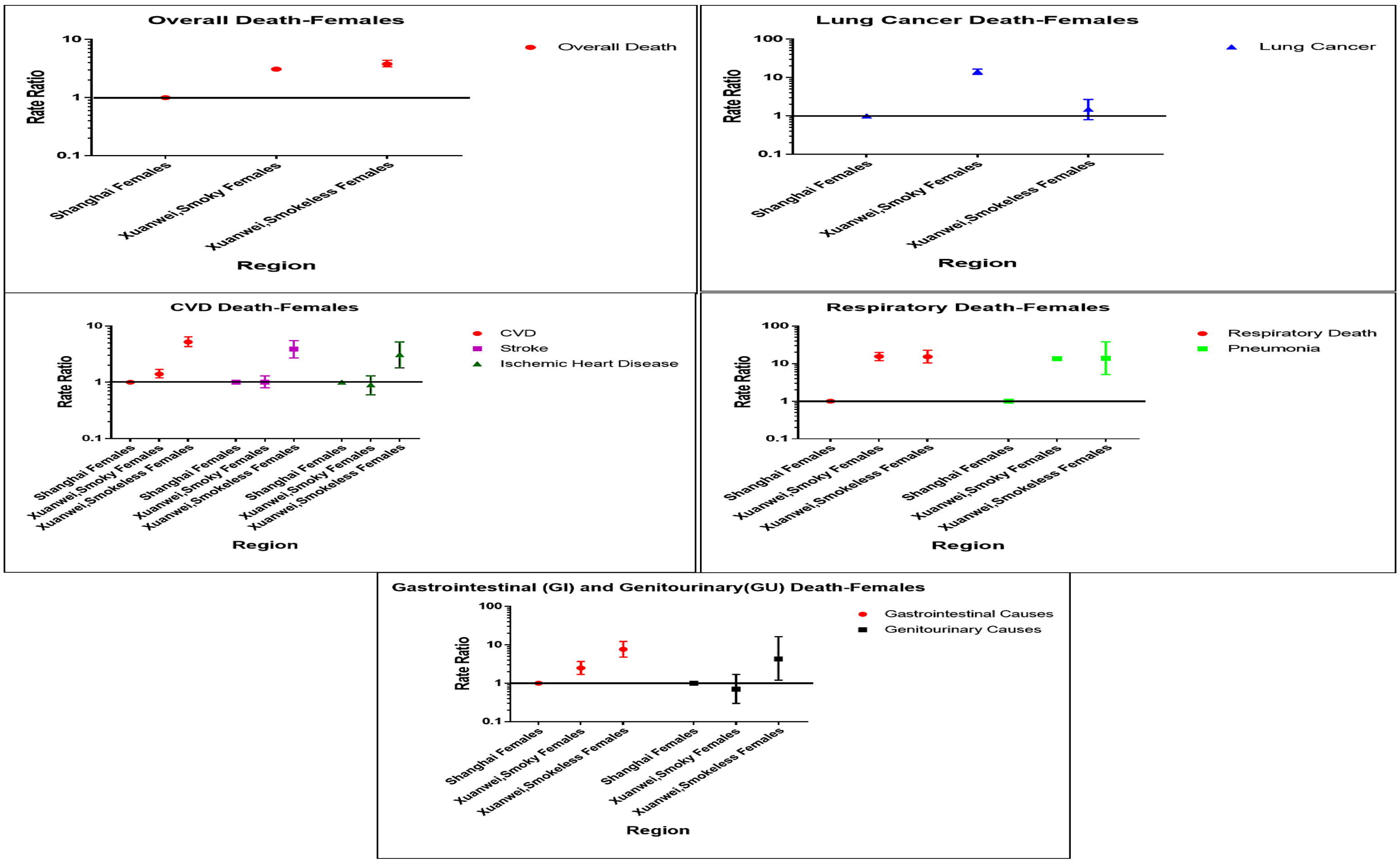


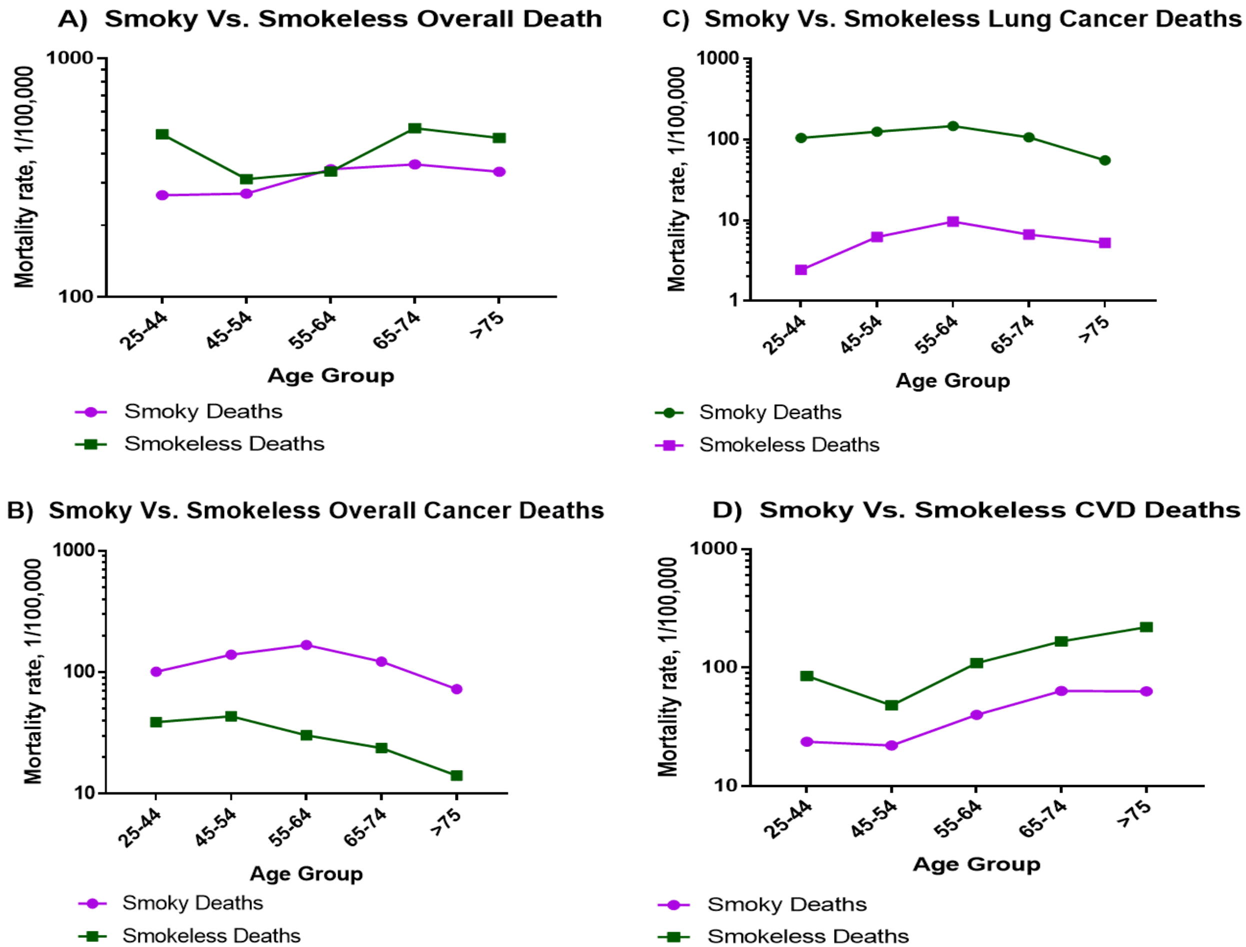
Figure 3: The rate ratio comparison between Shanghai women and Xuanwei women among overall mortality, lung cancer, and CVD, Respiratory, GI and GU.

Appendix:

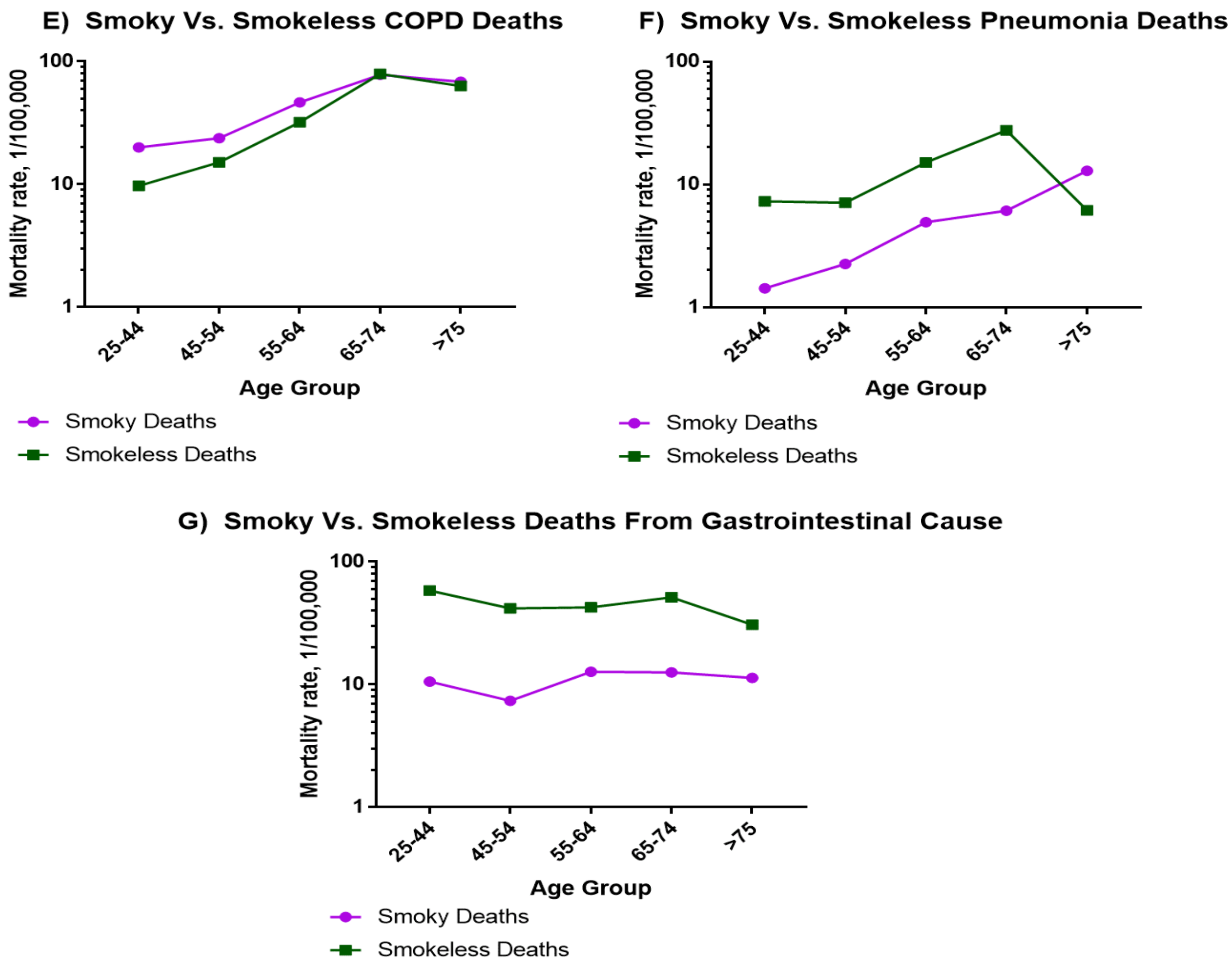
Supplemental Table 1: Average age of Death by Sex and Lifetime Type of Coal Use

Males	**N**	**Average age of Death**[1]	**STD Dev**[2]	**Females**	**N**	**Average age of Death**	**STD Dev**
Overall Death	9629	63.4	11.9	*Overall Death*	8020	62.9	11.9
Lung Cancer	2508	60.2	10.2	*Lung Cancer*	2132	59.3	10.0
CVD	1799	67.5	10.3	*CVD*	1519	66.2	11.7
Ischemic Heart Disease	188	67.3	10.2	*Ischemic Heart Disease*	120	69.5	11.2
Stroke	687	68.4	10.0	*Stroke*	465	67.3	11.6
COPD	1341	67.2	10.3	*COPD*	1241	65.9	10.4
Pneumonia	199	67.5	10.4	*Pneumonia*	167	67.2	11.0
Smoky	**N**	**Average age of Death**	**STD Dev**	**Smokeless**	**N**	**Average age of Death**	**STD Dev**
Overall Death	11520	61.4	11.6	*Overall Death*	2886	64.5	11.8
Lung Cancer	4144	59.1	10.0	*Lung Cancer*	49	63.8	9.4
CVD	1530	64.8	11.1	*CVD*	926	67.7	10.5
Ischemic Heart Disease	161	67.7	10.2	*Ischemic Heart Disease*	77	67.0	11.4
Stroke	650	66.2	10.6	*Stroke*	227	69.0	10.5
COPD	1752	65.1	10.5	*COPD*	330	68.4	8.8
Pneumonia	188	67.8	11.4	*Pneumonia*	109	64.7	8.3

Supplemental Figure 1- Age Specific Mortality Rates Among Smoky and Smokless Coal:

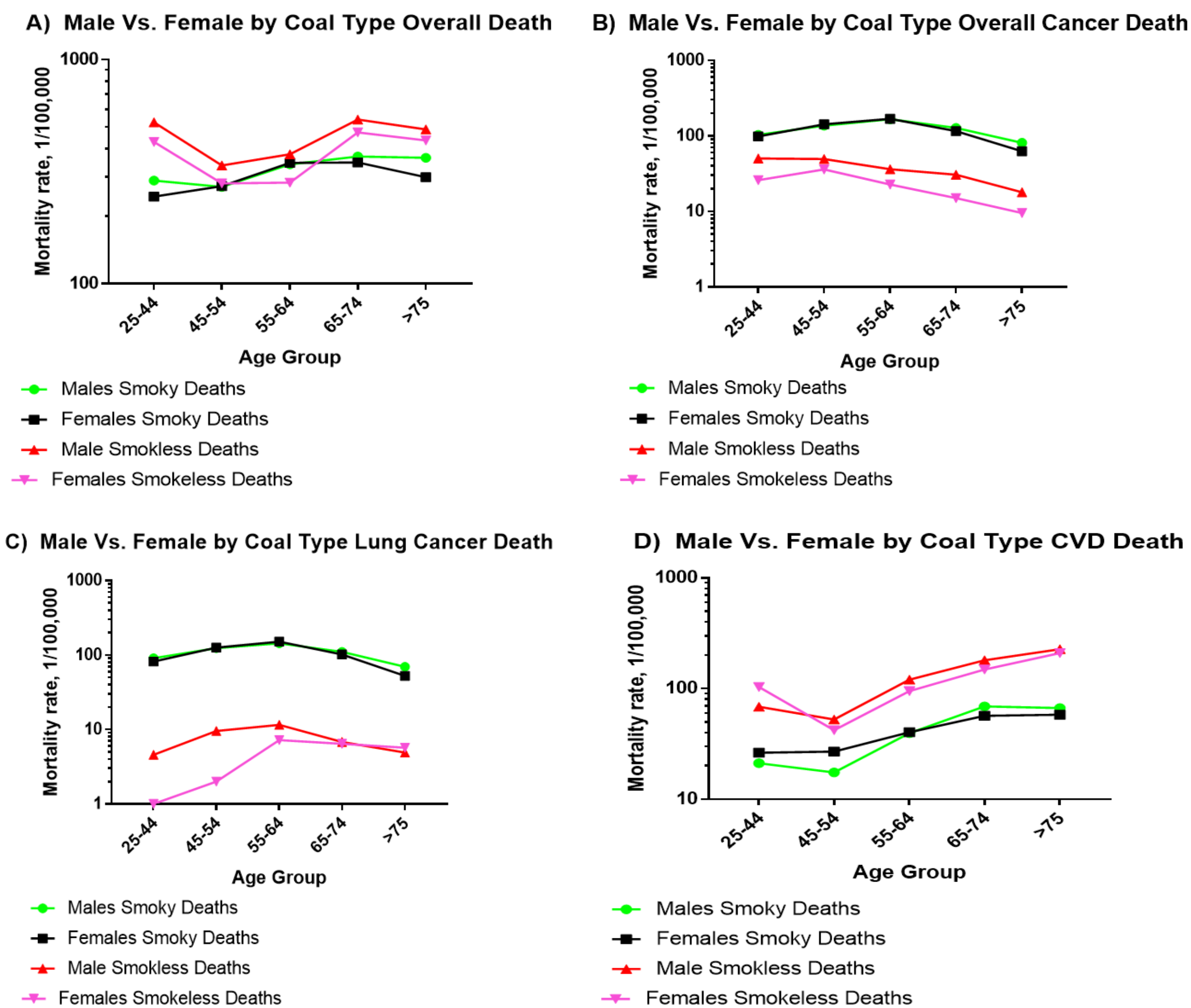


Supplemental Figure 1 Cont.:



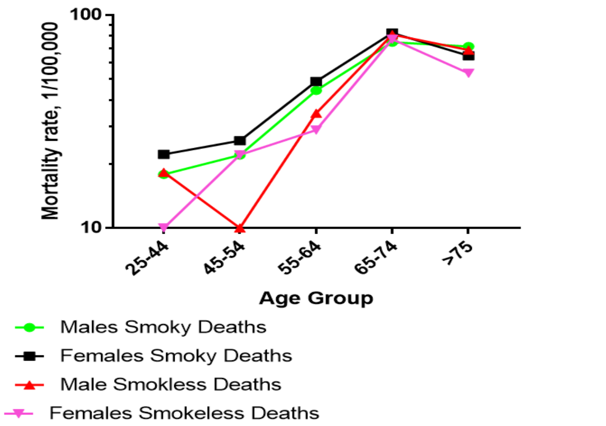
Supplemental Figure 1. Age specific mortality rates were obtained stratified by age group and coal exposure. Overall (A), Cancer (B), Lung Cancer(C), CVD (D), COPD (E), Pneumonia (F), and GI (G) mortality were identified.

Supplemental Figure 2- Age Specific Mortality Rates Among Smoky and Smokless Coal and Sex:

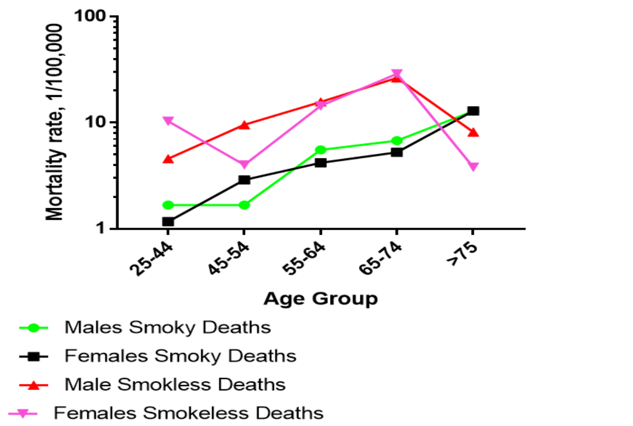


Supplemental Figure 2 Cont.:

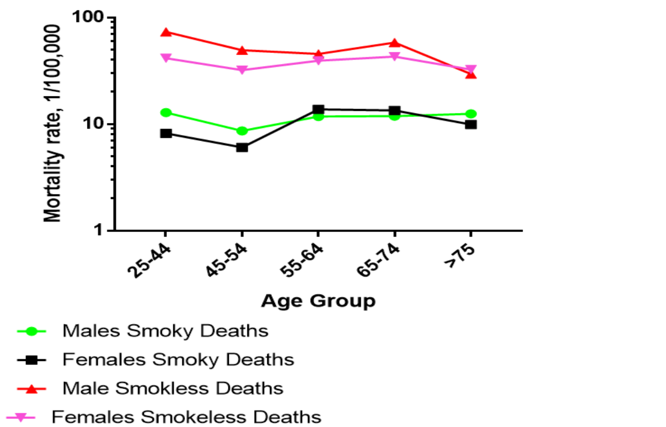
E) Male Vs. Female by Coal Type COPD Death



F) Male Vs. Female by Coal Type Pneumonia Death

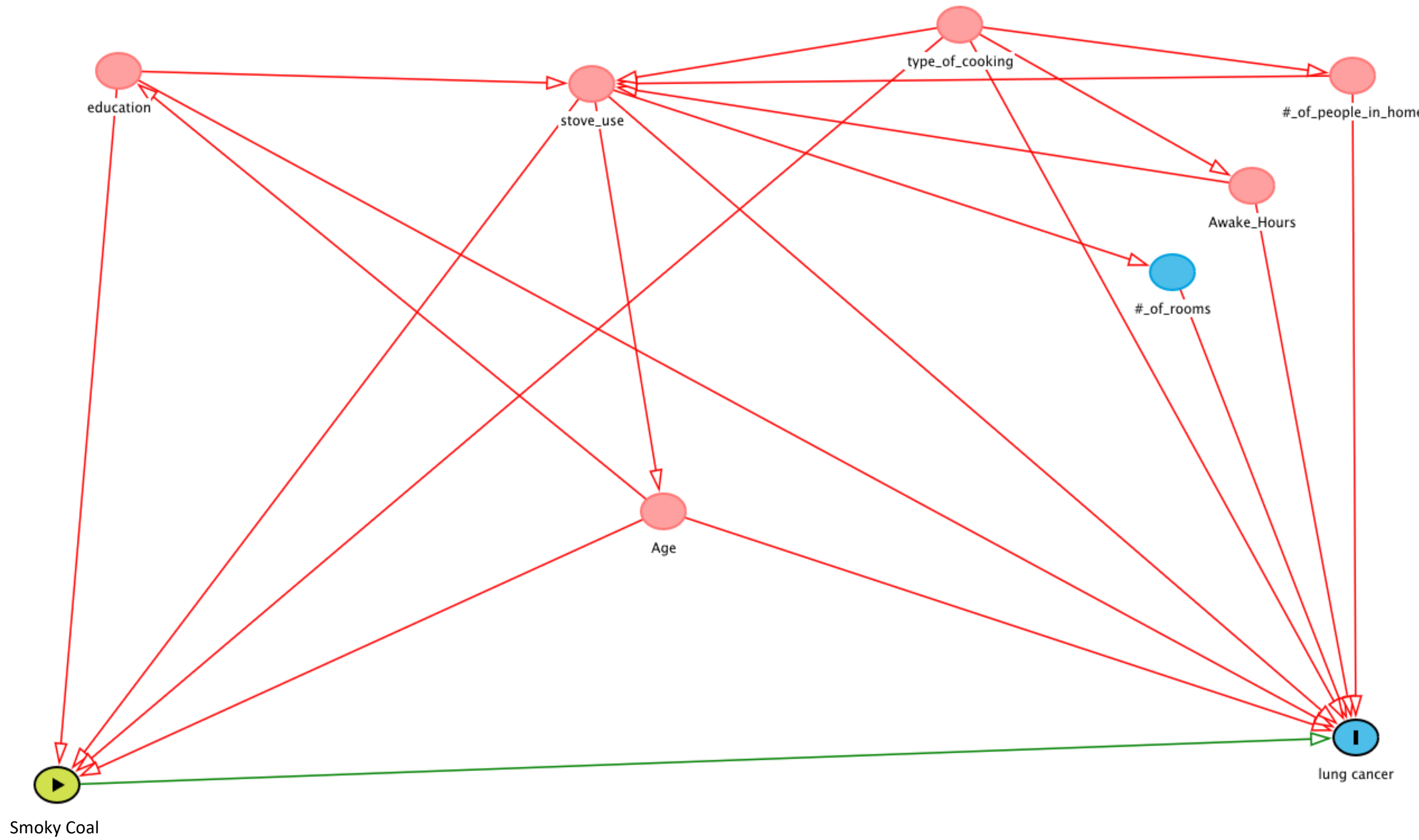


G) Male Vs. Female by Coal Type Gastrointestinal Cause



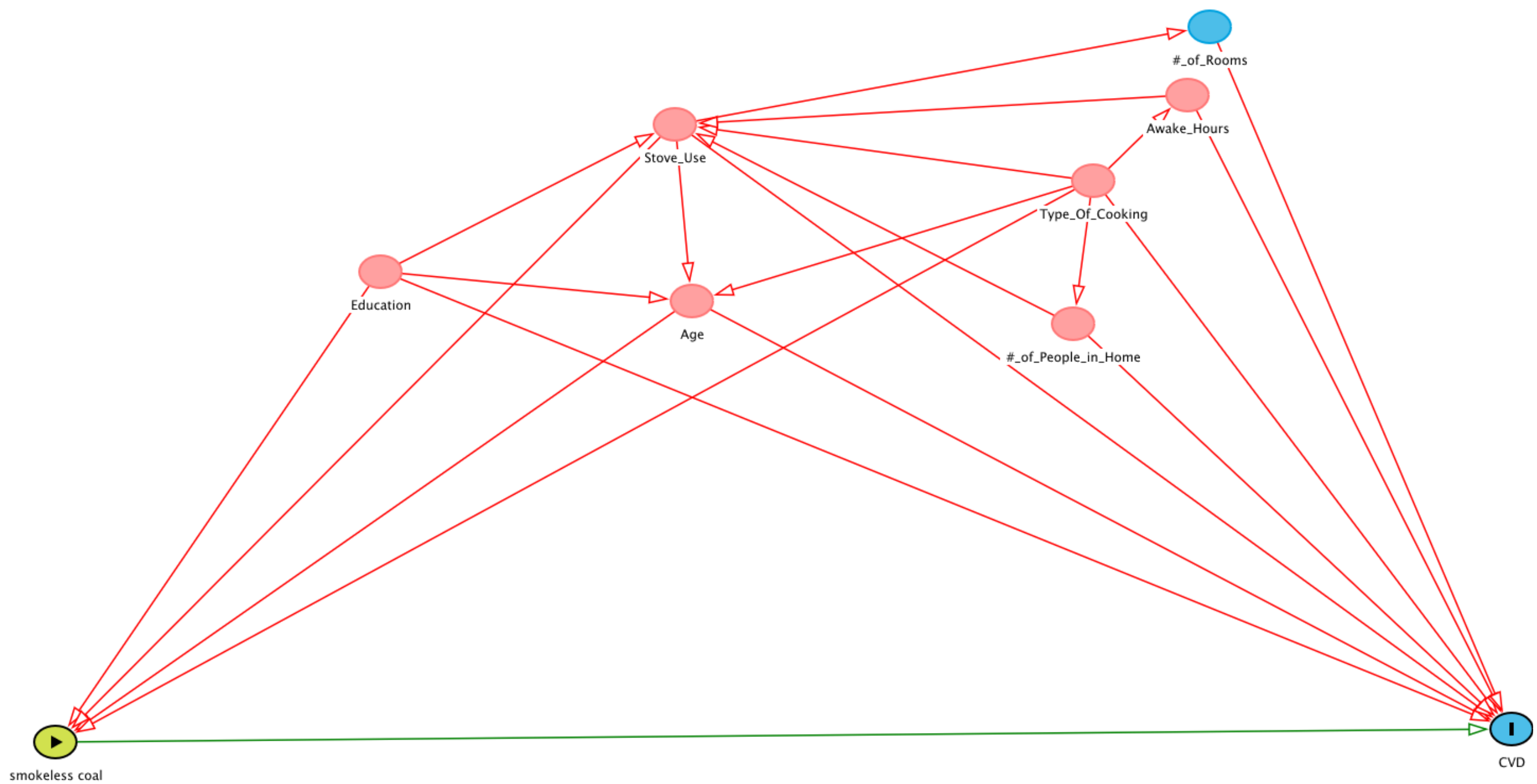
Supplemental Figure 2. Age specific mortality rates were obtained stratified by age group and coal exposure, and sex. Overall(A), Cancer(B), Lung Cancer(C), CVD(D), COPD (E), Pneumonia (F), and GI(G) mortality were identified.

Supplemental Figure 3: Smoky Coal DAG



Supplemental Figure 3. Directed Ayclical Graph for the exposure of smoky coal and the outcome of lung cancer is depicted. The variables on interest that were eventually controlled for in the Cox models were, education, age, type of cooking, number of rooms, number of hours awake in home, stove use, and the number of hours spent awake in home.

Supplemental Figure 4: Smokeless Coal DAG



Supplemental Figure 4. Directed Ayclical Graph for the exposure of smokeless coal and the outcome of CVD is depicted. The variables on interest that were eventually controlled for in the Cox models were, education, age, type of cooking, number of rooms, number of hours awake in home, stove use, and the number of hours spent awake in home.