## RESEARCH



# Short-term exposure to outdoor nitrogen dioxide and respiratory mortality, with high-risk populations: a nationwide time-stratified case-crossover study

Hyewon Yun<sup>1</sup>, Seoyeong Ahn<sup>2</sup>, Jieun Oh<sup>3</sup>, Cinoo Kang<sup>3</sup>, Ayoung Kim<sup>3</sup>, Dohoon Kwon<sup>3</sup>, Sojin Ahn<sup>1</sup>, Jiwoo Park<sup>2</sup>, Jinah Park<sup>3</sup>, Ejin Kim<sup>4</sup>, Ho Kim<sup>2</sup> and Whanhee Lee<sup>5,6\*</sup>

### Abstract

Numerous existing studies reported the negative impacts of outdoor nitrogen dioxide (NO<sub>2</sub>) on respiratory mortality. However, the evidence of related high-risk populations was considerably limited, especially associated with ages, causes of death, and district-level characteristics. In addition, most earlier studies were based on monitored areas, thus previous risk estimates of NO<sub>2</sub> could be biased to provide nationwide risk estimates and high-risk populations. Therefore, this study performed a nationwide time-stratified case-crossover study to evaluate the association between short-term ambient NO<sub>2</sub> and respiratory mortality in South Korea (2015–2019). A machine learning-ensemble daily NO<sub>2</sub> prediction model was used to cover unmonitored areas. To examine high-risk populations, we assessed NO<sub>2</sub> risk estimates by age group, sex, cause of mortality, and district-level characteristics. In the total population, NO<sub>2</sub> was weakly associated with increased mortality risk due to respiratory disease (OR [odds ratio]: 1.011, 95% CI [confidence interval]: 0.995–1.027), and the association became evident only in individuals aged 80 y or older (1.022, 1.000-1.044), especially related to pneumonia. Further, in people aged 60–69 years, NO<sub>2</sub> was marginally associated with mortality for chronic lower respiratory diseases. Lower district-level socioeconomic status and medical services were marginally related to higher respiratory mortality risks related to NO<sub>2</sub>. The excess respiratory mortality fractions and YLL (year of life lost) attributable to NO<sub>2</sub> were 4.13% and 93,851.63 years, and around 70% of the excess deaths were due to noncompliance with the World Health Organization air guality guidelines (daily average NO<sub>2</sub> > 25  $\mu$ g/ m<sup>3</sup>). This study provides evidence for high-risk populations and the appropriateness of target-specific action plans against NO<sub>2</sub>. In addition, based on the excess death estimates, we suggest stricter NO<sub>2</sub> standards are required.

Keywords Nitrogen dioxide, Respiratory mortality, High-risk populations

\*Correspondence: Whanhee Lee whanhee.lee@pusan.ac.kr Full list of author information is available at the end of the article



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#### Introduction

 $NO_2$  has been known as a common outdoor air pollutant that has hazardous impacts on the respiratory system [22].  $NO_2$  is involved in the secondary formation of fine particulate matter [31], and it is one of the highly reactive nitrogen oxides ( $NO_x$ ) from high-temperature combustion processes. Traffic, power plants, and off-road equipment are the major contributors to ambient  $NO_2$ concentrations [10, 17, 37], thus  $NO_2$  concentrations have been considered a proxy of traffic-related air pollutant levels [1].

Historically, multiple human or animal toxicology studies [20] identified that  $NO_2$  is a major risk factor for dysfunctions in the respiratory system including respiratory infections, [11], asthma [1], and decreasing pulmonary function [40]. Existing in vitro and experimental studies revealed that exposure to  $NO_2$  increases oxidative stress, inflammatory response to inhaled allergen in bronchi, and the reactive oxygen and nitrogen species [3, 4].  $NO_2$ inhalation also can lead to lung malfunctions, accelerate pulmonary infections, and degenerate lung diseases through a pro-inflammatory response (which is an automatic immune response) [20].

Furthermore, the association between outdoor NO<sub>2</sub> and respiratory mortality is less understood, compared to particulate matter and ozone [37]. First, because many previous studies have investigated the association between NO<sub>2</sub> and all-cause or non-accidental mortality [31, 32], epidemiological evidence for the NO<sub>2</sub> risk of respiratory mortality with more specific causes of death was limited, despite plausible biological mechanisms we mentioned earlier, such as oxidative stress, inflammatory response, and increased pulmonary infections. Second, since monitoring stations were generally operated in metropolitan urban areas or industrial areas, many relevant studies have investigated well-monitored areas [31, 32]. This point suggests that previous NO<sub>2</sub> risk estimates might be biased due to limited information on less-monitored [16]. Third, to our knowledge, few studies have examined spatial differences in NO2-related respiratory mortality risks depending on regional characteristics with large data [37], although examining regional differences could be important for effective and righteous public health resource allocation and mobilization. Lastly, studies on the excess mortality burden attributable to NO<sub>2</sub> were limited.

To address these gaps in knowledge, we performed a nationwide time-stratified case-crossover study, with the national respiratory mortality records and a machine learning-based NO<sub>2</sub> prediction model from 2015 through 2019 in South Korea. To reveal detailed high-risk populations, this study examined the heterogeneous associations between NO<sub>2</sub> and respiratory mortality by age

group, cause of death, sex, and district-level characteristics. Further, we estimated the excess mortality burdens due to the entire NO<sub>2</sub> and due to NO<sub>2</sub> concentrations above the 2021 World Health Organization (WHO) air quality guidelines (daily average NO<sub>2</sub> > 25  $\mu$ g/m<sup>3</sup>).

#### Methodology

#### **Study populations**

This study included all people residing in South Korea who died of respiratory disease and were registered in Statistics Korea. We obtained individual-level respiratory mortality data covering all 247 districts of inland South Korea (except Jeju and Ulleung islands) from 2015 to 2019. The International Classification of Disease 10th Revision (ICD-10) was used to define respiratory death in our study (ICD-10: J00–J99).

However, due to the identification problem, Statistics Korea only provides the causes of respiratory death based on the three-character "category of the diagnosis" of ICD-10. Thus, we could collect three specific causes of respiratory death: pneumonia (J12–J18), chronic lower respiratory diseases [CLR] (J40–J47), and other respiratory diseases (respiratory diseases that were not classified into the above three specific diseases). We were unable to analyze the mortality for influenza separately because of the small sample size (less than 3,000 cases, annually). Thus, we classified influenza into the "other respiratory disease" category.

Further, to examine the different associations between  $NO_2$  and mortality by age, we classified ages at death into five categories: total (all ages), individuals aged 0–59 y, 60–69 y, 70–79 y, and those aged 80 or older.

#### Study design

This study adopted a time-stratified case-crossover design to estimate the association between  $NO_2$  and respiratory mortality. This approach has been recognized as a standardized method to estimate the association between short-term exposure to air pollution and health outcomes [21, 25] by controlling for time-invariant (or less variant) confounders and time trends. Detailed explanations of the study design are in the Supplementary Materials ("1. Study design").

#### Air pollution and environmental data

We collected nationwide district-level modeled NO<sub>2</sub> (ppm) and PM<sub>2.5</sub> ( $\mu$ g/m<sup>3</sup>) from machine-learning ensemble prediction models from 2015 to 2019 (study years). These models were developed by the AiMS-CREATE team and their models were used in previous published studies [24, 33]. More detailed information on the ensemble prediction model is provided in the Supplemental Materials, "2. Air pollution prediction models". The

prediction models for daily NO<sub>2</sub> and PM<sub>2.5</sub> showed good performances during the study period: cross-validated  $R^2$  values of 0.95 and 0.94 (Table S1). Although previous studies used a relatively short lag period of  $NO_2$  (e.g., lag 0–1) as the main exposure [6, 12, 15, 31], several studies reported that the impacts of air pollution on respiratory outcome could have longer lag days; some existing studies suggested the plausible mechanisms that exacerbation of respiratory infections would be expected to take more time [38, 39] and complex interactions between air pollutants and antioxidants in the lung lining fluid compartment could contribute to the delayed deterioration of respiratory reactions [34]. Therefore, we tried to find an optimal moving average period of  $NO_2$  (up to a week) based on the lowest Akaike Information Criterion (AIC). As a result, the average NO2 from the same day to five lag days (lag 0-5) was selected as the main exposure.

We also collected district-level 2 m air temperature (K), relative humidity (%), and precipitation (m) from the ERA-5 Land global reanalysis dataset [7]. This ERA-5 dataset has a horizontal resolution of  $0.1^{\circ} \times 0.1^{\circ}$ , thus we assigned it to each district by averaging the values at grid cells with centroid points inside the boundary of each district [35].

#### **District indicators**

To examine the effect modifications by district-level characteristics, we obtained data on six indicators covering urbanicity, accessibility to parks, health behaviors, and socioeconomic levels. Detailed information on data sources and explanations of the selected district indicators is in the Supplementary Materials ("3. District-level indicators"). Briefly, we first collected population density (persons per km<sup>2</sup>) to address different urbanicity [26]. Second, to examine the urban green spaces [8, 19], the accessibility to parks in the living sphere (hereafter, park accessibility; distance to neighboring parks from each grid) was collected. Third, we obtained two variables related to regional health behaviors: the proportions of current smoking and obesity [23]. To examine the effect modification by regional socioeconomic status, we collected the proportion of people who received the National Basic Livelihood Security and the proportion of people who could not visit the medical facilities when they wanted within a year [23]. We classified each indicator into three categories (high, middle, and low) based on their tertiles for the statistical analysis [8].

#### Statistical analysis

We created a time-stratified case-crossover dataset for each age group, cause of death, and sex (a total of 40 combinations in the main analysis: five age categories, sexes, and four respiratory deaths). For each case day (i.e., date of death), we set matched control days as days with the same day of the week and month within the same year. This time-stratified self-matching controls the confounding from time-invariant variables or variables that do not change substantially in a month, such as body mass index, and diet [45]. Further, the bidirectional time-stratified matching also controlled for potential confounding for the day of the week, seasonality, and long-term trends of NO<sub>2</sub> and outcomes [28]. We performed a conditional logistic regression to evaluate the associations between short-term exposure to NO<sub>2</sub> and respiratory mortality in each case-crossover dataset.

As the main analysis, we performed NO<sub>2</sub> single pollutant models. To control for potential confounding, we adjusted for relative humidity, precipitation (as linear terms with lag 0-1), and temperatures (lag 0-3) with a natural cubic spline with six degrees of freedom based on previous large studies on air pollution and mortality [6, 29, 31]; however, it was also based on our grid search for optimal modeling specifications based on the lowest Akaike Information Criterion. We measured the association between short-term NO<sub>2</sub> and respiratory mortality with odd ratios (ORs) for a 0.01 ppm (10 ppb) increase in lag 0-5 NO<sub>2</sub>. In addition, to check the potential nonlinear relationship between NO<sub>2</sub> (0-5) and respiratory mortality, we conducted a conditional logistic regression with a natural cubic spline (including equally spaced three internal knots for  $NO_2$ ), instead of the linear term of  $NO_2$ in the main model.

To find high-risk districts, we performed analyses to examine which district-level characteristics modify the association between  $NO_2$  and respiratory mortality. For each case-crossover dataset divided by causes of death, we added an interaction term between  $NO_2$  and categorized district indicators (tertiles) and repeated the main analysis. The time-stratified self-matching design already controlled the potential confounding from district-level characteristics that did not change within a month, thus the interaction was included in a conditional logistic model individually for each indicator.

We performed sensitivity analyses to examine the consistency of our results in relation to different modeling specifications and two pollutant models ( $PM_{2.5}$  adjusted). Across all statistical analyses, R software (version 4.2.1) with package "*survival*" was used.

## Excess respiratory mortality and Years of life lost from mortality attributable to NO<sub>2</sub>

To assess the excess respiratory mortality burden due to short-term exposure to  $NO_2$ , we translated our estimated ORs into excess deaths and YLL (years of life lost from mortality) attributable to  $NO_2$ . Detailed processes for the excess respiratory mortality burden estimation are in the

Supplementary Materials ("4. Estimation of the excess respiratory mortality burden attributable to short-term exposure to ambient NO2"). Briefly, we first allocated the individual YLLs based on the national life expectancy estimation in 2019 (Statistics Korea 2024). Based on the estimated ORs from the main analysis, we calculated daily and total excess deaths and YLL, and the total excess deaths ratio with the total number of respiratory deaths provide the total excess fraction (%) of respiratory deaths attributable to short-term NO<sub>2</sub> exposures. Further, to assess the excess mortality burden due to noncompliance with the current 2021 WHO guidelines, we calculated excess respiratory deaths and YLL only for the subset of days with NO<sub>2</sub> levels above (i.e. non-compliance) the WHO air quality guidelines (daily average  $NO_2 > 25 \ \mu g/m^3$ ).

#### Results

Table 1 shows descriptive statistics of respiratory mortality during the study period. During the study period, a total of 161,059 mortality cases were included in this study. Among causes of respiratory death, pneumonia, CLR, and other respiratory diseases showed 95,201 (59.1%), 33,478 (20.8%), and 32,380 (20.1%) cases, individually. Percentages for the causes of respiratory death were calculated as a proportion of the total number of respiratory disease cases. Individuals aged 80 y or older showed the largest mortality counts for (total) respiratory disease (103,271; 55.7%) and males showed higher counts (89,687) than females (71,371). Figure 1 presents the average geographical distribution of average  $NO_2$  (left) during the study period (0.012 ppm on average) and total respiratory death counts (right).

Figure 2 exhibits a nonlinear association between  $NO_2$ and respiratory mortalities. Except for mortality due to other respiratory diseases, mortality due to respiratory diseases had an approximately linear association with short-term exposure to  $NO_2$ . Mortality due to other respiratory diseases also showed a positively linear association with  $NO_2$  after around 0.015 ppm.

Figure 3 presents the cause-specific associations between  $NO_2$  and respiratory mortality in the total age and by age group. In the total age, the associations between  $NO_2$  and respiratory mortality were observed, with an OR of 1.022 with 95% CIs: 1.004–1.040. The association with respiratory disease was not evident in people aged less than 80 y, and those aged 80 y or older only showed an association with  $NO_2$ : OR: 1.034 (95% CI: 1.012–1.057). Other respiratory disease deaths (pneumonia, CLR, and other respiratory diseases) also showed the similar age pattern: individuals aged 80 y or older showed the highest ORs. Figure S1 displays the age-specific association between  $NO_2$  and respiratory mortality by sex.

Table	1	Descriptive statistics	on respiratory	mortality data th	ìе
study	us	ed (2015–2019)			

Causes of death	Age categories	Case	%
Respiratory disease	Total	161,059	100.0
	0–59 y	6,396	4.0
	60–69 y	11,741	7.3
	70–79 y	39,628	24.6
	80 y and older	103,271	64.1
	Females	71,372	44.3
	Males	89,687	55.7
Pneumonia	Total	95,201	59.1
	0–59 y	3,709	2.3
	60–69 y	5,847	3.6
	70–79 y	21,100	13.1
	80 y and older	64,531	40.1
	Females	45,529	28.3
	Males	49,672	30.8
Chronic lower respiratory diseases	Total	33,478	20.8
	0–59 y	884	0.5
	60–69 y	2580	1.6
	70–79 y	8964	5.6
	80 y and older	21,043	13.1
	Females	12,248	7.6
	Males	21,230	13.2
Other respiratory diseases	Total	32,380	20.1
	0–59 y	1803	1.1
	60–69 y	3314	2.1
	70–79 y	9564	5.9
	80 y and older	17,697	11.0
	Females	13,595	8.4
	Males	18,785	11.7

Based on the point estimates, we could not observe risk differences between females and males.

Figure 4 shows the associations between  $NO_2$  and respiratory death depending on district indicator categories in the total population. *P*-values in Fig. 3 indicate the statistical test results on the effect modification (i.e. differences in ORs for middle or high levels compared to OR for low levels). We could not find statistically evident effect modifications by district characteristic for the total respiratory deaths. While the association between  $NO_2$  and pneumonia death was lower in high density areas than in low density areas (P-value: 0.060). Except for it, we could not find a consistent effect modification.

Figure 5 displays the effect modifications by districtlevel indications in the associations between  $NO_2$  and respiratory death depending on two age groups (individuals aged 50–59 y and aged 80 or older). We could not find a consistent effect modification pattern between the two age groups. The marginal effect modification of the



Fig. 1 Geographical distributions of the district-level averages of daily average NO<sub>2</sub> (ppm [left]) and total death counts [right] in South Korea from 2015 through 2019. NO<sub>3</sub>: nitrogen dioxide



**Fig. 2** Nonlinear associations between exposure to NO<sub>2</sub> (lag 0–5) and respiratory mortalities. **A** total respiratory deaths, **B** Deaths due to pneumonia, **C** Deaths due to chronic lower respiratory diseases, **D** Deaths due to other respiratory diseases (not classified into pneumonia or chronic lower respiratory-related deaths). NO<sub>2</sub>: Nitrogen dioxide (ppm)

Causes of death	OR (95% CI)	P-value	
Respiratory disease		1.022 (1.004, 1.040)	0.014
0–59 years		0.997 (0.918, 1.083)	0.944
60–69 years		1.013 (0.951, 1.079)	0.676
70–79 years	<del></del>	0.999 (0.966, 1.033)	0.962
80 years and older		1.034 (1.012, 1.057)	0.002
Pneumonia	+	1.017 (0.995, 1.039)	0.141
0–59 years	<del>_</del>	1.007 (0.904, 1.122)	0.902
60–69 years		0.979 (0.895, 1.071)	0.649
70–79 years		1.000 (0.954, 1.048)	0.996
80 years and older	<b></b>	1.028 (1.000, 1.057)	0.052
Chronic lower respiratory diseases	÷	1.029 (0.989, 1.070)	0.153
0–59 years 🔶 🛀		0.962 (0.766, 1.208)	0.738
60–69 years		0.993 (0.873, 1.130)	0.913
70–79 years		0.997 (0.927, 1.072)	0.935
80 years and older		1.057 (1.004, 1.112)	0.034
Other respiratory diseases		1.029 (0.991, 1.068)	0.128
0–59 years		0.996 (0.856, 1.158)	0.959
60–69 years		1.090 (0.973, 1.221)	0.141
70–79 years		1.002 (0.937, 1.071)	0.961
80 years and older	· · · · · · · · · · · · · · · · · · ·	1.037 (0.985, 1.091)	0.162
0.8	1 1.1	25	
	Odds Ratio		

Fig. 3 Associations between short-term NO<sub>2</sub> exposure (lag 0–5) and respiratory mortality by age group and cause of respiratory mortality. NO<sub>2</sub>: nitrogen dioxide. Odd ratios (ORs) for a 0.01 ppm (10 ppb) increase in NO<sub>2</sub>

proportion of National Basic Livelihood Security Recipient was observed only in individuals aged 80 or older, especially related to pneumonia and CLR deaths. The corresponding results to Fig. 4 for people aged 60–69 y and 70–79 y are exhibited in Figure S2, and we could not observe evident differences between the two age groups. In addition, although we could not find pronounced differences in effect modification patterns between sexes, the effect modifications by the proportion of Unmet medical needs were marginally more prominent in females than in males based on the point estimates (Figure S3).

Table 2 displays the estimated excess mortality and YLL attributable to short-term  $NO_2$  exposures by cause of death. For respiratory mortality, the excess mortality fraction attributable to  $NO_2$  was 4.13 (95% CI: 0.87–7.40). Based on the point estimates, the excess fraction was higher in CLR mortality (5.29%) than pneumonia mortality in the total age. Further, the excess respiratory mortality fraction attributable to  $NO_2$  due to noncompliance with WHO air quality guidelines was 3.06%, and it accounted for over 60% of the total excess respiratory mortality attributable to  $NO_2$ . Table S2 reports the excess mortality numbers attributable to  $NO_2$ ; the absolute number of excess deaths was the highest in pneumonia deaths due to the large numbers of pneumonia

deaths. Table 2 also shows the excess YLL attributable to NO<sub>2</sub>, and the excess YLL was 93,851.63 years (95% CI: 19,779.11 years–167,983.69 years) for respiratory mortality in the total population, and it was the highest for pneumonia death (42,261.11 years, -13,775.96.24 years–97,815.11 years) compared to other causes of respiratory death.

Lastly, in the sensitivity analyses (Table S3), we could observe that our risk estimates in the total and by age groups were generally less affected by different modeling specifications.

#### Discussion

This study assessed the nationwide association between short-term exposure to  $NO_2$  and respiratory mortality in South Korea from 2015 through 2019. To our knowledge, this is the first and largest nationwide study addressing the association between  $NO_2$  and respiratory mortality as well as the excess respiratory mortality burden due to  $NO_2$  in South Korea. We found that the association between  $NO_2$  and respiratory disease was the strongest in people aged 80 y or older compared to other age groups, especially for pneumonia death. Although the statistical evidence was weak, we found marginal effect modifications by certain district-level characteristics. Particularly, a higher proportion of National Nasic Liveliuhood

Population density Low		01 (35 % 01)	P-value
Population density Low			
LOW		1 020 /0 040 1 127)	
Middle	_	1.056 (1.019, 1.095)	0.729
High	-	1.013 (0.994, 1.033)	0.597
Park accessibility			
Low	-	1.016 (0.997, 1.035)	
Middle		1.042 (1.005, 1.079)	0.209
High % Current Smoking		1.055 (0.971, 1.146)	0.378
low	-	1.025 (1.001, 1.048)	
Middle		1.023 (0.989, 1.058)	0.947
High		1.015 (0.983, 1.048)	0.627
% National Basic Livelihood Security Recipient			
Low	-	1.026 (1.004, 1.048)	
Middle	- T.	1.010 (0.981, 1.039)	0.378
% Obesity		1.036 (0.966, 1.090)	0.000
Low	-	1.019 (0.996, 1.042)	
Middle		1.035 (1.006, 1.065)	0.394
High	+	1.002 (0.961, 1.045)	0.488
% Unmet medical needs			
Low	-	1.026 (0.997, 1.057)	
Middle		1.020 (0.994, 1.046)	0.733
High	1	1.019 (0.988, 1.052)	0.748
Population density			
Low		- 1.126 (1.001, 1.266)	
Middle		1.058 (1.009, 1.109)	0.321
High	+	1.005 (0.981, 1.030)	0.060
Park accessibility			
Low	<b>T</b> .	1.008 (0.984, 1.034)	0.475
widdle High		1.047 (0.999, 1.097)	0.149
% Current Smokina		1.004 (0.000, 1.184)	v.v.)2
Low	÷	1.018 (0.989, 1.049)	
Middle	-	1.013 (0.969, 1.059)	0.835
High		1.018 (0.977, 1.061)	0.993
% National Basic Livelihood Security Recipient	1		
Low	-	1.022 (0.993, 1.051)	
Middle	+	0.994 (0.957, 1.032)	0.232
High S Obosity		1.069 (1.003, 1.140)	0.192
Low	-	1.004 (0.975, 1.034)	
Middle		1.050 (1.012, 1.090)	0.055
High		0.991 (0.938, 1.047)	0.671
% Unmet medical needs			
Low		1.035 (0.996, 1.075)	
Middle	+	1.005 (0.972, 1.038)	0.232
High		1.017 (0.976, 1.059)	0.521
Population density			
Low -		0.930 (0.768, 1.128)	
Middle		1.080 (0.999, 1.168)	0.149
High		1.019 (0.975, 1.064)	0.361
Park accessibility		1.020 (0.976, 1.066)	
Park accessibility	- i	1 069 (0 989 1 156)	
Park accessibility Low Middle		0.074 (0.914, 1.165)	0.285
Park accessibility Low Middle High %Current Smoking		0.974 (0.814, 1.165)	0.285 0.619
Park accessibility Low Middle High ← % Current Smoking Low		0.974 (0.814, 1.165)	0.285 0.619
Park accessibility Low Middle High ← *% Current Smoking Low Middle –		0.974 (0.814, 1.165) 1.053 (0.998, 1.111) 1.000 (0.927, 1.078)	0.285 0.619 0.255
Park accessibility Low Middie → *(6 Current Smoking Low Middie → High		0.974 (0.814, 1.165) 1.053 (0.998, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086)	0.285 0.619 0.255 0.356
Para accessibility Low High 4 Current Smoking Cow Middie High 8 National Basic Livelihood Security Recipient		0.974 (0.814, 1.165) 1.053 (0.998, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086)	0.285 0.619 0.255 0.356
Para accessibility Low High Current Smoking Low Middie - High Static Livelihood Security Recipient Low		1.053 (0.986, 1.116) 0.974 (0.814, 1.165) 1.053 (0.998, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086)	0.285 0.619 0.255 0.356
Para accessibility Low Middin High % Current Smoking Low Middin % National Basic Livelihood Security Recipient Low Middin Low Middin		1.053 (0.986; 1.110) 0.974 (0.814, 1.165) 1.053 (0.998; 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086) 1.026 (0.976, 1.078) 1.038 (0.972, 1.108)	0.285 0.619 0.255 0.356
Para accessibility Low Middio High • • • • • • • • • • • • • • • • • • •		0.974 (0.814, 1.165) 1.053 (0.998, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086) 1.026 (0.976, 1.078) 1.038 (0.972, 1.109) 1.022 (0.919, 1.137)	0.285 0.619 0.255 0.356 0.767 0.953
Para accessibility Low Middia High Current Smoking Low Middia Kidon Sasic Livelihood Security Recipient Low Middia High High High Kobestly Low Low		0.974 (0.814, 1.165) 1.053 (0.998, 1.111) 1.000 (0.976, 1.078) 1.011 (0.941, 1.086) 1.026 (0.976, 1.078) 1.026 (0.976, 1.078) 1.022 (0.919, 1.137) 1.022 (0.919, 1.137)	0.285 0.619 0.255 0.356 0.767 0.953
Para accessionity Low Midde High • • • Succession Smoking Low Midde High • • National Basic Livelihood Sacurity Recipient Low Midde High • • Succession Sacurity Recipient Low Midde High • •		0.974 (0.814, 1.165) 1.053 (0.998, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086) 1.026 (0.976, 1.078) 1.028 (0.972, 1.109) 1.022 (0.919, 1.137) 1.025 (0.973, 1.079) 1.020 (0.966, 1.089)	0.285 0.619 0.255 0.356 0.767 0.953
Para accessibility Low Middia High • • • Scurrent Smoking Low Middia High • • Sk National Basic Livelihood Security Recipient Kow Middia High • • Low Middia High • •		0.974 (0.814, 1.165) 0.974 (0.814, 1.165) 1.053 (0.998, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086) 1.026 (0.976, 1.078) 1.028 (0.977, 1.079) 1.022 (0.918, 1.137) 1.025 (0.973, 1.079) 1.020 (0.956, 1.089) 1.026 (0.970, 1.168)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.921
Para accessibility Low Middio High Current Smoking Low Middio High So Automation Static Livelihood Security Recipient Low Middio High So Obesity High High High High High High High High		0.9374 (0.08.14, 1.168) 0.9374 (0.08.14, 1.168) 1.053 (0.998, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086) 1.026 (0.977, 1.078) 1.022 (0.973, 1.1079) 1.022 (0.973, 1.079) 1.022 (0.956, 1.089) 1.065 (0.970, 1.168)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468
Para accessibility Low Midde High Common Security Recipient Low Midde Kathena Basic Livelihood Security Recipient Low Midde High Cow Kathena Basic Livelihood Security Recipient Low Midde High Kathena Basic Livelihood Security Recipient Low Midde Low Midde Low Midde Low Kathena Basic Livelihood Security Recipient Low Kathen		1 026 (0.986 1.103) 1 027 (0.814 , 1.165) 1 025 (0.986 , 1.111) 1 000 (0.927, 1.078) 1 011 (0.941, 1.086) 1 026 (0.976, 1.078) 1 026 (0.971, 1.109) 1 022 (0.919, 1.137) 1 020 (0.966, 1.089) 1 026 (0.970, 1.169) 1 032 (0.966, 1.103)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468
Para accessibility Low Middia High Courrent Smoking Low Middia High K National Basic Livelihood Security Recipient High High Kulanda Basic Livelihood Security Recipient Low Middia High Kulanda Basic Livelihood Kulanda Recipient Low Middia High Kulanda Recipient Ku		0.574 (0.814, 1.165) 1.053 (0.908, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086) 1.026 (0.976, 1.079) 1.022 (0.918, 1.137) 1.025 (0.973, 1.079) 1.025 (0.973, 1.079) 1.026 (0.970, 1.169) 1.032 (0.966, 1.039) 1.042 (0.986, 1.104)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830
Para accessibility Low Middle High Current Smoking Low Middle High % National Basic Livelihood Security Recipient Low Middle High % Obesity High High High High High High High High		0.574 (0.814, 1.165) 1.053 (0.982, 1.078) 1.053 (0.982, 1.078) 1.011 (0.941, 1.089) 1.028 (0.972, 1.099) 1.028 (0.972, 1.109) 1.028 (0.972, 1.109) 1.028 (0.973, 1.079) 1.028 (0.973, 1.079) 1.028 (0.973, 1.199) 1.028 (0.984, 1.104) 1.026 (0.931, 1.086)	0.285 0.819 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593
Para accessibility Low Middle Low Middle Low Middle High Notent Stacking Low Middle High Sector Stacking Low Middle High Sector Stacking High Para Sector Stacking High High High High High High High Hig		0.974 (0.814, 1.165) 1.053 (0.908, 1.111) 1.000 (0.827, 1.078) 1.011 (0.941, 1.086) 1.028 (0.976, 1.078) 1.028 (0.977, 1.09) 1.022 (0.918, 1.377) 1.029 (0.918, 1.397) 1.029 (0.956, 1.089) 1.065 (0.970, 1.169) 1.032 (0.966, 1.103) 1.042 (0.968, 1.104) 1.009 (0.937, 1.069)	0.285 0.819 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593
Para accessibility Low Midde High Cov Sourcent Smoking Low Midde High Kutional Basic Livelihood Security Recipient Low Midde High Kutional Basic Livelihood Security Recipient Low Midde High Sourcent State Low Midde High Sourcent Midde High Sourcent Midde High Low Midde High Sourcent Midde High Low Midde High Sourcent Midde High Cov Midde High Cov Midde High Cov Cov Midde High Cov		0.974 (0.814, 1.165) 1.053 (0.986, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086) 1.026 (0.976, 1.079) 1.026 (0.978, 1.079) 1.026 (0.973, 1.079) 1.026 (0.973, 1.079) 1.038 (0.977, 1.169) 1.038 (0.977, 1.169) 1.042 (0.986, 1.103) 1.042 (0.983, 1.104) 1.042 (0.983, 1.104) 1.042 (0.983, 1.104) 1.042 (0.983, 1.104)	0.285 0.619 0.255 0.356 0.953 0.921 0.468 0.830 0.593
Para accessionity Low Midde Low Midde Hiph Coment Smoking Low Midde Hiph National Basic Livelihood Sacurity Recipient Low Midde Hiph % Obenity Low Midde Hiph % Unmet medical needs Low Midde		0.574 (0.814, 1.165) 1.053 (0.982, 1.078) 1.010 (0.927, 1.078) 1.011 (0.941, 1.089) 1.026 (0.976, 1.076) 1.028 (0.972, 1.109) 1.022 (0.919, 1.377) 1.025 (0.973, 1.079) 1.025 (0.973, 1.079) 1.025 (0.961, 1.039) 1.042 (0.983, 1.104) 1.042 (0.983, 1.104)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593
Para accessibility Low Middia High • • • • • • • • • • • • • • • • • • •		0.974 (0.814, 1.165) 1.053 (0.986, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086) 1.025 (0.976, 1.078) 1.025 (0.976, 1.079) 1.022 (0.919, 1.137) 1.025 (0.976, 1.079) 1.022 (0.919, 1.137) 1.025 (0.976, 1.079) 1.025 (0.956, 1.089) 1.032 (0.966, 1.103) 1.042 (0.986, 1.103) 1.042 (0.986, 1.103) 1.042 (0.986, 1.104) 1.006 (0.937, 1.060) 0.922 (0.749, 1.135) 1.023 (0.951, 1.135) 1.025 (0.951, 1.135)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593
Para accessibility Low Middia High Current Smoking Low Middia High Kutional Basic Livelihood Security Recipient Kutional Recipient Kutional Basic Livelihood Security Recipient Kutional Recipien		0.574 (0.814, 1.165) 1.053 (0.982, 1.074) 1.053 (0.982, 1.074) 1.026 (0.927, 1.078) 1.026 (0.976, 1.078) 1.026 (0.976, 1.078) 1.026 (0.971, 1.079) 1.022 (0.919, 1.137) 1.025 (0.917, 1.179) 1.025 (0.961, 1.089) 1.026 (0.963, 1.041) 1.026 (0.963, 1.041) 1.026 (0.937, 1.080) 0.922 (0.749, 1.135) 1.029 (0.961, 1.135) 1.029 (0.961, 1.135)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593
Para accessibility Low Midde High Com Midde State Low Midde Kather Katheral Basic Livelihood Security Recipient Low Midde Katheral Basic Livelihood Security Recipient Katheral Basic Livelihood Security Recipient Low Midde Katheral Basic Livelihood Security Recipient Low Midde Katheral Basic Livelihood Security Recipient Low Midde Katheral Basic Livelihood Security Recipient Low Midde Katheral Basic Livelihood Security Recipient		0.574 (0.814, 1.165) 1.053 (0.908, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.068) 1.028 (0.972, 1.109) 1.028 (0.972, 1.109) 1.028 (0.972, 1.109) 1.028 (0.971, 1.079) 1.028 (0.971, 1.079) 1.028 (0.971, 1.079) 1.028 (0.971, 1.169) 1.028 (0.937, 1.069) 1.028 (0.937, 1.069) 1.028 (0.937, 1.069) 0.928 (0.748, 1.135) 1.029 (0.950, 1.115) 1.029 (0.950, 1.115) 1.031 (0.991, 1.073) 1.033 (0.992, 1.075)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593
Para accessibility Low Middia Low Securent Smoking Low Middia Securent Smoking Low Middia High Securent Smoking Low Middia High So Obesity So Obesity So Uncert medical needs Low Middia High Strume medical needs High High Strume medical needs High High Strume medical needs High High High Strume medical needs High High High High High High High High		0.574 (0.314, 1.165) 1.053 (0.988, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.086) 1.026 (0.976, 1.078) 1.022 (0.918, 1.137) 1.022 (0.918, 1.137) 1.022 (0.918, 1.137) 1.022 (0.918, 1.137) 1.022 (0.956, 1.059) 1.022 (0.956, 1.059) 1.022 (0.956, 1.059) 1.022 (0.956, 1.159) 1.022 (0.956, 1.159) 1.022 (0.956, 1.159) 1.022 (0.951, 1.157) 1.022 (0.951, 1.157) 1.023 (0.961, 1.157) 1.033 (0.991, 1.177) 1.033 (0.991, 1.177)	0.225 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593
Para accessibility Low Middle High Com Notified Low Middle High National Basic Livelihood Sacurity Recipient Low Middle High Su Obesity Low Middle High Polarison density Low Middle High Polarison density Low Middle High Para accessibility Low Middle High Para sacurational High Para sacurational High High Para sacurational High High Para sacurational High High Para sacurational Para sacuratio		0.574 (0.814, 1.165) 1.053 (0.982, 1.078) 1.053 (0.982, 1.078) 1.011 (0.941, 1.089) 1.028 (0.972, 1.099) 1.028 (0.972, 1.099) 1.028 (0.972, 1.099) 1.028 (0.972, 1.099) 1.028 (0.970, 1.169) 1.029 (0.968, 1.030) 1.029 (0.968, 1.030) 1.029 (0.968, 1.137) 1.029 (0.991, 1.073) 1.033 (0.991, 1.073) 1.033 (0.992, 1.075) 1.031 (0.925, 1.085) 1.131 (0.035, 1.368)	0.225 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593 0.593
Para accessibility Low Midde Figh Cov Midde Kow Kode Kow Kow Kode Kow Kow Kode Kow		0.577 (0.814, 1.165) 1.053 (0.908, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.065) 1.028 (0.976, 1.078) 1.028 (0.977, 1.09) 1.022 (0.918, 1.377) 1.022 (0.918, 1.377) 1.025 (0.918, 1.377) 1.026 (0.937, 1.089) 1.032 (0.966, 1.033) 1.042 (0.968, 1.103) 1.042 (0.968, 1.103) 1.042 (0.968, 1.103) 1.042 (0.968, 1.103) 1.042 (0.937, 1.089) 0.922 (0.476, 1.155) 1.043 (0.937, 1.089) 1.043 (0.926, 1.033) 1.043 (0.926, 1.043) 1.043 (0.926, 1.043) 1.044 (0.926, 1.043) 1.044 (0.946, 1.043) 1	0.285 0.619 0.255 0.356 0.767 0.983 0.983 0.983 0.488 0.830 0.593
Para accessibility Low Midde High Courrent Smoking Low Midde High Midde High Kutional Basic Livelihood Security Recipient Low Midde High Kutional Basic Livelihood Security Recipient Low Midde High Kutional Basic Livelihood Security Recipient Kutional Security Secu		0.974 (0.814, 1.165) 1.053 (0.987, 1.078) 1.053 (0.987, 1.078) 1.026 (0.977, 1.078) 1.026 (0.977, 1.078) 1.026 (0.971, 1.079) 1.022 (0.919, 1.137) 1.026 (0.971, 1.079) 1.026 (0.971, 1.079) 1.026 (0.987, 1.079) 1.026 (0.987, 1.089) 1.032 (0.949, 1.135) 1.032 (0.949, 1.135) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.992, 1.089) 1.010 (0.925, 1.089) 1.010 (0.927, 1.089) 1.010 (0.927, 1.089) 1.010 (0.927, 1.089) 1.010 (0.927, 1.089) 1.010 (0.927, 1.089) 1.010 (0.927, 1.089)	0.285 0.619 0.255 0.386 0.767 0.953 0.921 0.468 0.830 0.593 0.324 0.294 0.352
Para accessibility Low Midde High Cow Midde High National Basic Livelihood Security Recipient Low Midde High So Obesity Cow Midde High So Unent Recical needs Low Midde High Population density Eopulation density High Para accessibility Low Midde High So Comesty Low Midde High Cow Midde Cow M		0.974 (0.814, 1.165) 1.053 (0.982, 1.078) 1.015 (0.982, 1.078) 1.011 (0.941, 1.089) 1.026 (0.976, 1.078) 1.026 (0.976, 1.078) 1.026 (0.976, 1.078) 1.026 (0.976, 1.078) 1.026 (0.976, 1.078) 1.026 (0.983, 1.104) 1.026 (0.983, 1.104) 1.026 (0.983, 1.104) 1.026 (0.983, 1.104) 1.026 (0.983, 1.104) 1.026 (0.983, 1.104) 1.026 (0.983, 1.104) 1.036 (0.971, 1.078) 1.033 (0.991, 1.073) 1.033 (0.992, 1.1075) 1.033 (0.992, 1.1075) 1.033 (0.992, 1.1075) 1.033 (0.992, 1.1075) 1.033 (0.992, 1.1075) 1.033 (0.992, 1.075) 1.033 (0.992, 1.075) 1.033 (0.992, 1.075) 1.030 (0.951, 1.079) 1.030 (0.971, 1.070) 1.030 (0.971, 1.0	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593 0.593 0.593 0.593
Para accessibility Low Midde Low Midde Upto Surrent Smoking Low Midde High Katlonal Basic Livelihood Security Recipient Low Midde High Surrent medical needs Low Midde High Para accessibility Low Midde Low Low Midde Low		0.577 (0.814, 1.165) 1.053 (0.908, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.068) 1.026 (0.976, 1.078) 1.027 (0.971, 1.09) 1.022 (0.971, 1.09) 1.022 (0.971, 1.09) 1.029 (0.966, 1.089) 1.065 (0.970, 1.169) 1.009 (0.937, 1.089) 0.922 (0.749, 1.135) 1.029 (0.968, 1.103) 1.029 (0.961, 1.157) 1.031 (0.991, 1.079) 1.019 (0.971, 1.079) 1.019 (0.971, 1.079) 1.019 (0.971, 1.079) 1.019 (0.944, 1.082)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593 0.324 0.294 0.294 0.352 0.352 0.352
Para accessibility Low Midde High Cov Stational Basic Livelihood Security Recipient Low Midde High Para accessibility Low Midde H		0.974 (0.814, 1.165) 1.053 (0.982, 1.074) 1.053 (0.982, 1.074) 1.050 (0.927, 1.078) 1.026 (0.972, 1.076) 1.026 (0.972, 1.076) 1.026 (0.971, 1.079) 1.022 (0.919, 1.137) 1.025 (0.919, 1.137) 1.025 (0.937, 1.079) 1.025 (0.943, 1.044) 1.006 (0.937, 1.085) 0.922 (0.749, 1.135) 1.031 (0.991, 1.073) 1.033 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.935, 1.368) 1.019 (0.971, 1.070) 1.071 (0.944, 1.022) 1.026 (0.944, 1.022) 1.039 (0.944, 1.023) 1.039 (0.944, 1.023) 1.039 (0.944, 1.023) 1.039 (0.944, 1.023) 1.039 (0.944, 1.023) 1.039 (0.944, 1.023) 1.039 (0.941, 1.070) 1.039 (0.941, 1.072) 1.039 (0.941, 1.042) 1.039 (0.941, 1.042) 1.039 (0.941, 1.042) 1.039 (0.941, 1.042) 1.040 (0.941, 1.042) 1.040 (0.941, 1.042)	0.285 0.619 0.255 0.386 0.767 0.953 0.921 0.468 0.830 0.293 0.324 0.294 0.294 0.352 0.352 0.352
Para accessibility Low Midde Low High Storent Smoking Low Midde High Kational Basic Livelihood Security Recipient Low Midde High Storest Kow Midde High Storest Cow Midde High Population density Low Midde High Para accessibility Low Midde High Para Scessibility Low Midde High Storest High Para Scessibility Low Midde High High Para Scessibility Low Midde High High Para Scessibility Low Midde High High Note High High High High High High High High		0.974 (0.814, 1.165) 1.053 (0.982, 1.078) 1.010 (0.927, 1.078) 1.011 (0.941, 1.068) 1.026 (0.972, 1.079) 1.026 (0.973, 1.079) 1.026 (0.973, 1.079) 1.026 (0.973, 1.079) 1.026 (0.971, 1.079) 1.026 (0.961, 1.03) 1.046 (0.937, 1.069) 1.046 (0.937, 1.069) 1.046 (0.937, 1.069) 1.046 (0.937, 1.069) 1.031 (0.941, 1.073) 1.031 (0.941, 1.073) 1.036 (0.921, 1.079) 1.037 (0.925, 1.038) 1.047 (0.921, 1.079) 1.047 (0.921, 1.079) 1.047 (0.921, 1.079) 1.047 (0.921, 1.079) 1.047 (0.921, 1.079) 1.047 (0.944, 1.062) 1.038 (0.991, 1.068)	0.285 0.619 0.255 0.356 0.767 0.983 0.921 0.468 0.830 0.593 0.324 0.294 0.294 0.294 0.352 0.205 0.838 0.838
Para accessibility Low Middia High S Urrent Smoking Low Middia High High S National Basic Livelihood Security Recipient Low Middia High S Unmet medical needs Low Middia High S Unmet medical needs Low Middia High C Cow Middia High C Cow Middia High C Cow Middia High S Current Smoking Low Middia High S National Basic Livelihood Security Recipient Low Middia High S Current Smoking Low Middia High S National Basic Livelihood Security Recipient Low Mid		0.577 (0.814, 1.165) 1.053 (0.908, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.065) 1.028 (0.976, 1.078) 1.028 (0.976, 1.078) 1.028 (0.977, 1.09) 1.029 (0.918, 1.937) 1.029 (0.918, 1.937) 1.029 (0.968, 1.103) 1.029 (0.968, 1.103) 1.029 (0.968, 1.103) 1.029 (0.968, 1.103) 1.029 (0.968, 1.103) 1.029 (0.969, 1.155) 1.029 (0.937, 1.069) 0.922 (0.749, 1.155) 1.029 (0.937, 1.069) 0.922 (0.749, 1.155) 1.029 (0.937, 1.069) 1.031 (0.991, 1.053) 1.031 (0.991, 1.053) 1.039 (0.971, 1.079) 1.039 (0.991, 1.065) 1.039 (0.971, 1.079) 1.039 (0.991, 1.065) 1.039 (0.991, 1.066) 1.039 (0.991, 1.066) 1.031 (0.991, 1.066) 1	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593 0.324 0.294 0.294 0.382 0.382 0.388 0.882 0.882
Para accessibility Low Midde High Com Midde FisCurrent Smoking Low Midde High Su Obesity Low Midde High Su Obesity Low Midde High Su Obesity Low Midde High Su Come Su Composition High Ana accessibility Low Midde High Para accessibility Low Midde High Su Come Su Composition High High Su Come Su Composition High High High High High High High High		0.974 (0.814, 1.165) 1.053 (0.982, 1.078) 1.015 (0.982, 1.078) 1.011 (0.941, 1.089) 1.026 (0.972, 1.078) 1.036 (0.972, 1.069) 1.022 (0.919, 1.137) 1.022 (0.919, 1.137) 1.025 (0.956, 1.089) 1.026 (0.968, 1.03) 1.042 (0.983, 1.104) 1.026 (0.937, 1.089) 1.026 (0.983, 1.104) 1.026 (0.937, 1.089) 1.033 (0.984, 1.104) 1.033 (0.994, 1.105) 1.033 (0.994, 1.105) 1.030 (0.994, 1.105) 1.030 (0.994, 1.107) 1.030 (0.994, 1.108) 1.019 (0.971, 1.079) 1.036 (0.991, 1.086) 1.038 (0.991, 1.086) 1.038 (0.991, 1.086) 0.987 (0.986, 1.079)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593 0.324 0.294 0.470 0.352 0.352 0.355 0.838 0.862 0.235
Para accessibility Low Midde High Steams Standard Standar		0.977 (0.814, 1.165) 1.053 (0.908, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.068) 1.026 (0.972, 1.079) 1.026 (0.972, 1.079) 1.026 (0.972, 1.079) 1.026 (0.972, 1.109) 1.026 (0.970, 1.109) 1.026 (0.961, 1.03) 1.026 (0.961, 1.03) 1.046 (0.937, 1.069) 0.920 (7.46, 1.35) 1.029 (0.961, 1.03) 1.029 (0.961, 1.03) 1.029 (0.961, 1.03) 1.029 (0.961, 1.03) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.997, 1.070) 1.031 (0.997, 1.070) 1.031 (0.997, 1.070) 1.031 (0.997, 1.070) 1.031 (0.997, 1.070) 1.031 (0.991, 1.068) 1.031 (0.964, 1.062) 1.036 (0.991, 1.068) 1.031 (0.964, 1.079) 1.054 (1.006, 1.105)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.593 0.324 0.294 0.324 0.294 0.324 0.295 0.838 0.838 0.838
Para accessibility Low Midde Uow Securent Smoking Low Securent Smoking Low Midde High Securent Smoking Low Midde High Securent Midde High Securent Midde High Securent Midde High Para accessibility Low Midde High Securent Smoking Low Midde High High High High High High High High		0.974 (0.814, 1.165) 1.053 (0.987, 1.078) 1.053 (0.987, 1.078) 1.026 (0.976, 1.078) 1.026 (0.976, 1.078) 1.026 (0.971, 1.079) 1.022 (0.919, 1.137) 1.025 (0.919, 1.137) 1.025 (0.973, 1.079) 1.025 (0.971, 1.199) 1.025 (0.963, 1.040) 1.026 (0.963, 1.040) 1.026 (0.963, 1.040) 1.026 (0.937, 1.060) 0.922 (0.749, 1.135) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.031 (0.991, 1.073) 1.032 (0.991, 1.073) 1.031 (0.991, 1.073) 1.032 (0.991, 1.073) 1.034 (1.004, 1.054) 1.036 (0.991, 1.073) 1.036 (0.991, 1.091) 1.036 (0.911, 1.091)	0.285 0.619 0.255 0.356 0.767 0.983 0.983 0.983 0.983 0.983 0.468 0.593 0.352 0.324 0.235 0.352 0.352 0.235 0.838 0.862 0.235
Para accessibility Low Midde Filiph Com Midde Filiph Para accessibility Low Midde Filiph Para accessibility Low Midde Filiph Com Filiph Co		0.974 (0.814, 1.165) 1.053 (0.982, 1.078) 1.051 (0.927, 1.078) 1.011 (0.941, 1.089) 1.026 (0.972, 1.078) 1.026 (0.973, 1.079) 1.022 (0.919, 1.377) 1.025 (0.973, 1.079) 1.022 (0.947, 1.078) 1.022 (0.947, 1.078) 1.022 (0.948, 1.104) 1.022 (0.948, 1.104) 1.022 (0.948, 1.104) 1.026 (0.947, 1.089) 1.032 (0.948, 1.104) 1.033 (0.941, 1.065) 1.031 (0.941, 1.062) 1.032 (0.946, 1.078) 1.034 (0.941, 1.062) 1.034 (0.941, 1.062) 1.034 (0.941, 1.062) 1.034 (0.941, 1.062) 1.036 (0.941, 1.062) 1.036 (0.941, 1.062) 1.036 (0.941, 1.062) 1.036 (0.941, 1.062) 1.036 (0.941, 1.062) 1.036 (0.941, 1.061) 1.036 (0.941, 1.062) 1.036 (0.941, 1.061) 1.036 (0.941, 1.062) 1.036 (0.941, 1.062) 1.036 (0.941, 1.062) 1.036 (0.941, 1.061) 1.036 (0.941, 1.062) 1.036 (0.941, 1.061) 1.036 (0.941, 1.062) 1.036 (0.941, 1.061) 1.036 (0.941, 1.061) 1.036 (0.941, 1.061) 1.036 (0.945, 1.071) 0.977 (0.981, 1.071)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.468 0.830 0.255 0.324 0.234 0.234 0.235 0.324 0.235 0.388 0.888 0.888 0.236 0.236 0.236
Para accessibility Low Midde Low Midde Units Low Midde Kather Kather Low Midde High Kather Ka		0.577 (0.814, 1.165) 1.053 (0.908, 1.111) 1.000 (0.927, 1.078) 1.011 (0.941, 1.065) 1.028 (0.976, 1.078) 1.028 (0.977, 1.109) 1.029 (0.972, 1.109) 1.029 (0.966, 1.039) 1.029 (0.966, 1.039) 1.029 (0.966, 1.039) 1.042 (0.966, 1.103) 1.042 (0.966, 1.103) 1.042 (0.966, 1.103) 1.042 (0.966, 1.103) 1.042 (0.968, 1.104) 1.039 (0.977, 1.109) 1.039 (0.977, 1.099) 0.922 (0.749, 1.138) 1.043 (0.937, 1.089) 0.922 (0.749, 1.138) 1.039 (0.937, 1.089) 0.922 (0.749, 1.138) 1.031 (0.937, 1.368) 1.011 (0.925, 1.033) 1.039 (0.927, 1.079) 1.011 (0.925, 1.033) 1.019 (0.971, 1.079) 1.010 (0.944, 1.082) 1.036 (0.946, 1.079) 1.054 (1.006, 1.165) 1.054 (1.006, 1.165)	0.285 0.619 0.255 0.386 0.767 0.953 0.953 0.953 0.953 0.953 0.953 0.468 0.294 0.470 0.382 0.382 0.205 0.838 0.838 0.838 0.225 0.838
Para accessionity Low Middle High Com Norden		0.974 (0.814, 1.165) 1.053 (0.982, 1.074) 1.053 (0.982, 1.074) 1.050 (0.927, 1.078) 1.026 (0.972, 1.079) 1.026 (0.972, 1.079) 1.026 (0.972, 1.079) 1.025 (0.919, 1.137) 1.025 (0.919, 1.137) 1.025 (0.943, 1.044) 1.026 (0.937, 1.085) 1.035 (0.961, 1.034) 1.036 (0.937, 1.085) 0.922 (0.749, 1.135) 1.031 (0.991, 1.073) 1.033 (0.991, 1.073) 1.033 (0.991, 1.073) 1.036 (0.937, 1.085) 1.019 (0.971, 1.079) 1.026 (0.964, 1.044) 1.039 (0.994, 1.045) 1.039 (0.964, 1.044) 1.039 (0.964, 1.044) 1.039 (0.964, 1.045) 1.039 (0.964, 1.074) 1.046 (0.964, 1.074)	0.285 0.619 0.255 0.386 0.767 0.953 0.521 0.468 0.593 0.593 0.593 0.593 0.593 0.593 0.593 0.593 0.593 0.593 0.294 0.294 0.295
Para accessibility Low Midde High Steers Smoking Low Midde High Stational Basic Livelihood Security Recipient Low Midde High Stational Basic Livelihood Security Recipient Low Midde High Stational Recipient Low Midde High Para accessibility Low Midde High Para accessibility Low Midde High Stational Basic Livelihood Security Recipient Low Midde High Stational Security Recipient Low		0.977 (0.814, 1.165) 1.053 (0.982, 1.078) 1.010 (0.927, 1.078) 1.010 (0.927, 1.078) 1.021 (0.941, 1.068) 1.022 (0.972, 1.079) 1.022 (0.971, 1.079) 1.022 (0.971, 1.079) 1.022 (0.961, 1.037) 1.026 (0.970, 1.169) 1.026 (0.963, 1.049) 1.026 (0.963, 1.049) 1.026 (0.937, 1.069) 1.026 (0.937, 1.069) 1.026 (0.937, 1.069) 1.026 (0.937, 1.069) 1.026 (0.937, 1.069) 1.026 (0.937, 1.069) 1.026 (0.937, 1.069) 1.031 (0.941, 1.073) 1.031 (0.941, 1.073) 1.036 (0.971, 1.070) 1.031 (0.941, 1.073) 1.036 (0.991, 1.068) 1.031 (0.964, 1.079) 1.054 (1.006, 1.155) 1.056 (0.945, 1.071) 1.006 (0.945, 1.071) 1.006 (0.945, 1.071) 1.006 (0.945, 1.071) 1.006 (0.945, 1.071) 1.007 (0.944, 1.065) 1.006 (0.945, 1.071) 1.001 (0.941, 1.065) 1.006 (0.945, 1.071) 1.001 (0.941, 1.065) 1.004 (0.941, 1.065) 1.005 (0.941, 1.065) 1.005 (0.941, 1.065) 1.004 (0.941, 1.065) 1.005 (0.941, 1.065)	0.285 0.619 0.255 0.356 0.767 0.953 0.921 0.921 0.921 0.921 0.921 0.921 0.921 0.921 0.921 0.923 0.921 0.923 0.923 0.9320 0.932 0.9320 0.9320 0.9320 0.932000000000000000000000000000

Fig. 4 Effect modifications by district-level indicators in the NO<sub>2</sub> (lag 0–5)-respiratory mortality risk in the total population. *P*-values indicate the statistical test results on the effect modification (i.e. magnitude of differences in estimates for middle or high-levels compared to low-level; not for the hypothesis that OR is one). %: proportion. NO<sub>2</sub>: nitrogen dioxide. Odd ratios (ORs) for a 0.01 ppm (10 ppb) increase in NO<sub>2</sub>

Security Recipient was marginally associated with higher  $NO_2$ -respiratory mortality risk, and the association was slightly more evident in people aged 80 y or older than other age groups. Lastly, we estimated the excess respiratory mortality burden attributable to short-term  $NO_2$  and found that over 60% of the excess burden attributable to  $NO_2$  was related to non-compliance with the current WHO air quality guidelines.

Our findings are generally consistent with previous studies. A multi-country study with a large dataset including 5.5 million mortality cases showed that shortterm NO<sub>2</sub> was associated with increased respiratory mortality risk [31]. One European multi-city study also revealed the short-term impact of NO<sub>2</sub> on increased respiratory mortality [38]. A systemic review study including 87 research articles from multiple continents reported that short-term NO<sub>2</sub> and mortality reported that a 0.01 ppm increase in NO<sub>2</sub> was associated with a 2.05% increase in respiratory mortality [43]. Our study estimated around a 1.1% increase in respiratory mortality per 0.01 ppm increase in NO<sub>2</sub>. However, it should be carefully interpreted because study periods and regions were heterogeneous between our study and the review study.

One of the novel findings of this study was examining the different associations between NO<sub>2</sub> and respiratory mortality by age group and the cause of respiratory death. We found that total respiratory mortality risk estimates related to NO<sub>2</sub> were the highest in people aged 80 or older, and the association was not generally observed in people less than 80 y. Whereas previous studies reported that the short-term NO<sub>2</sub> risks for respiratory disease-related mortalities became more evident in people aged around 65 y [9, 38, 42], which is much lower than our high-risk age. These discrepancies should be interpreted carefully because the traditional concept of "the elderly" might have changed in recent years. Due to the rapid advances in medicine and science, the overall health of people has consistently improved during recent decades, globally [14]. Although the evidence of this study is highly limited, we conjecture that the differences between previous studies and our findings regarding age group might be related to the research period of

	0–59 year OR (95% CI)	;	- Causes of death	8	OR (95% CI)	P-value
	1		Respiratory disease			
	0.027 (0.551.1.502)		Population density	1	1 009 (0 094 1 225)	
522	1.121 (0.945.1.329)		Middle	+	1.073 (1.026.1.123)	0.702
.897	0.971 (0.887,1.062)	+	High	-	1.024 (0.999,1.048)	0.215
			Park accessibility	1		
	0.986 (0.901,1.079)	- <u>+</u>	Low	1	1.026 (1.001,1.051)	
1.578	1.039 (0.876,1.233)		Middle		1.059 (1.013,1.107)	0.205
	1.000 (0.000,1.070)		% Current Smoking	-	1.100 (1.001,1.1.1.0)	0.140
	0.925 (0.824,1.039)	-	Low	-	1.038 (1.009,1.068)	
.358	1.010 (0.866,1.177)	+	Middle	+	1.025 (0.982,1.071)	0.622
.042	1.114 (0.965,1.287)	-	High	-	1.034 (0.992,1.077)	0.861
	0.090 (0.979 1.004)	1	% Obesity	1	1.020 (1.001.1.050)	
0.217	1.088 (0.953,1.241)		Middle		1.054 (1.016,1.093)	0.306
.238	0.857 (0.701,1.048)		High	÷	1.009 (0.957,1.064)	0.500
			% National Basic Livelihood Security Recipient	1		
	0.962 (0.865,1.069)	+	Low	+	1.046 (1.018,1.074)	
.236	1.061 (0.930,1.210)		Middle	t	1.000 (0.964,1.038)	0.048
.002	0.964 (0.772,1.254)		% Unmet medical needs		1.077 (1.011,1.140)	0.390
	0.957 (0.827,1.108)	4	Low	-	1.034 (0.997, 1.073)	
.118	1.109 (0.983,1.251)	-	Middle	-	1.037 (1.004,1.070)	0.926
.493	0.894 (0.776,1.029)	-	High	-	1.031 (0.991,1.072)	0.895
			Pneumonia			
	0.000 (0.470 4.040)		Population density	<u> </u>	1 130 (0 001 1 000)	
.779	1.030 (0.820 1 203)		Middle	-	1.139 (0.991,1.309) 1.064 (1.005 1.128)	0.368
.831	1.003 (0.891,1.129)	+	High	¥.	1.016 (0.986,1.047)	0.112
	,		Park accessibility	1		
	1.014 (0.900,1.142)	+	Low	÷	1.020 (0.989,1.051)	
.805	0.982 (0.781,1.235)	+	Middle	÷.	1.054 (0.996,1.115)	0.295
.890	0.973 (0.549,1.724)	_	High ·		1.0/4 (0.945,1.221)	0.432
	0.948 (0.814 1 105)	÷	26 Current Smoking	4	1.035 (0.999 1.079)	
.481	1.036 (0.845,1.271)	4	Middle	4-	1.025 (0.970,1.083)	0.771
.274	1.081 (0.895,1.306)		High	+	1.013 (0.962,1.067)	0.492
			% Obesity	1		
	0.986 (0.852,1.142)	+	Low	<u>t</u>	1.019 (0.983,1.056)	0.67
1.731 1.735	1.025 (0.863,1.216)	1	Middle	-	1.072 (1.025,1.122)	0.074
.730	1.039 (0.792,1.362)		Hign → % National Basic Livelihood Security Recipient		0.962 (0.899,1.029)	0.126
	0.961 (0.835.1.105)	4	Low	-	1.042 (1.007.1.079)	
0.371	1.060 (0.890,1.262)		Middle -	÷	0.982 (0.938,1.028)	0.034
.420	1.103 (0.806,1.510)		High		1.090 (1.007,1.180)	0.300
			% Unmet medical needs			
072	1.041 (0.861,1.259)	1	Low	1	1.049 (1.002,1.098)	0.210
).973 ) 974	1.045 (0.891,1.226)	1	Middle	Ξ	1.018 (0.978,1.059)	0.319
	0.020 (0.707,11110)		Chronic lower respiratory diseases	1	1.010 (0.000,1.071)	0.013
			Population density			
	0.600 (0.115,3.139)		Low —	-	1.074 (0.850, 1.358)	
0.440	1.168 (0.736,1.853)		Middle		1.113 (1.009,1.229)	0.777
0.613	0.921 (0.716,1.184)		High	1	1.039 (0.981,1.101)	0.786
	0.966 (0.751.1.241)			-	1 041 (0 983 1 104)	
0.903	0.997 (0.623,1.596)		Middle		1.096 (0.994, 1.209)	0.358
0.378	0.525 (0.137,2.015)		High -		- 1.133 (0.909,1.412)	0.460
			% Current Smoking	1		
	0.994 (0.714,1.383)	+	Low	-	1.068 (0.997,1.144)	
041	0.894 (0.584,1.368)		Middle -		1.001 (0.907,1.105)	0.275
1041	0.570 (0.000,1.400)		riigii	<u> </u>	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	0.786
			% Obesitv	-	1.085 (0.988,1.192)	0.786
	0.905 (0.665,1.232)	_	% Obesity Low		1.046 (0.977,1.119)	0.786
0.158	0.905 (0.665,1.232) 1.269 (0.875,1.841)		% Obesity Low Middle		1.046 (0.977,1.119) 1.038 (0.954,1.129)	0.786
.158	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104)		% <b>Obesity</b> Low Middle High		1.046 (0.977,1.119) 1.038 (0.954,1.129) 1.142 (1.013,1.288)	0.786 0.888 0.198
0.158 0.268	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104)		% Obesity Low Middle High % National Basic Livelihood Security Recipient		1.046 (0.977,1.119) 1.038 (0.954,1.129) 1.142 (1.013,1.288)	0.786 0.888 0.198
0.158 0.268 0.359	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.799 1.626)		% Obesity Low Middle High % National Basic Livelihood Security Recipient Low Middle Live		1.085 (0.988, 1.192) 1.046 (0.977, 1.119) 1.038 (0.954, 1.129) 1.142 (1.013, 1.288) 1.053 (0.987, 1.123) 1.057 (0.989, 1.153)	0.786 0.888 0.198
).158 ).268 ).359 ).283	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.799,1.636) 0.629 (0.326,1.214)		% Obesity           Low           High           % National Basic Livelihood Security Recipient           Low           Middle           High		1.085 (0.986,1.192) 1.046 (0.977,1.119) 1.038 (0.954,1.129) 1.142 (1.013,1.288) 1.053 (0.987,1.123) 1.057 (0.969,1.153) 1.076 (0.940,1.233)	0.786 0.888 0.198 0.941 0.769
.158 .268 .359 .283	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.799,1.636) 0.629 (0.326,1.214)		% Obesity Low Middle High % National Basic Livelihood Security Recipient Low Middle High - % Unmet medical needs		1.065 (0.986,1.192) 1.046 (0.977,1.119) 1.038 (0.954,1.129) 1.142 (1.013,1.288) 1.053 (0.987,1.123) 1.057 (0.969,1.153) 1.076 (0.940,1.233)	0.786 0.888 0.198 0.941 0.769
0.158 0.268 0.359 0.283	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.667,1.248) 1.143 (0.799,1.636) 0.629 (0.326,1.214) 1.057 (0.695,1.608)		% Obesity Low Middle High % National Basic Livelihood Security Recipient Low Middle High S Unmet medical needs Low		1.085 (0.986,1.192) 1.046 (0.977,1.119) 1.038 (0.954,1.129) 1.142 (1.013,1.288) 1.053 (0.967,1.123) 1.057 (0.969,1.153) 1.076 (0.940,1.233) 1.033 (0.947,1.126)	0.786 0.888 0.198 0.941 0.769
.158 .268 .359 .283	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.667,1.248) 1.143 (0.799,1.836) 0.629 (0.326,1.214) 1.057 (0.695,1.608) 1.046 (0.756,1.448)		% Obesity           Low           High           % National Basic Livelihood Security Recipient           Low           Middle           High           High           Work and the second security Recipient           Low           Middle           High           Low           Low           Middle           High           High		1.085 (0.986, 1.192) 1.046 (0.977, 1.119) 1.038 (0.954, 1.129) 1.142 (1.013, 1.288) 1.057 (0.969, 1.123) 1.076 (0.940, 1.233) 1.033 (0.947, 1.126) 1.037 (0.995, 1.157)	0.786 0.888 0.198 0.941 0.769 0.501
.158 .268 .359 .283 .968 .283	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.799,1.836) 0.629 (0.326,1.214) 1.057 (0.695,1.608) 1.046 (0.756,1.448) 0.775 (0.516,1.165)		** Obesity     Low     Middle     High     National Basic Livelihood Security Recipient     Low     Middle     High     ** Unmendical needs     Middle     High     Middle     High		1.068 (0.967,1.119) 1.046 (0.977,1.119) 1.038 (0.964,1.123) 1.142 (1.013,1.288) 1.057 (0.969,1.153) 1.057 (0.969,1.153) 1.076 (0.940,1.233) 1.033 (0.947,1.126) 1.033 (0.967,1.126)	0.786 0.888 0.198 0.941 0.769 0.501 0.672
0.158 0.268 0.259 0.283 0.968 0.283	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.799,1.836) 0.629 (0.326,1.214) 1.057 (0.695,1.608) 1.046 (0.756,1.448) 0.775 (0.516,1.165)		% Obesity Low Middle High % National Basic Livelihood Security Recipient Low Middle High - % Unmet medical needs Low Middle High Other respiratory disease Doubling Accentiv		1.068 (0.365,1.192) 1.046 (0.977,1.119) 1.038 (0.954,1.129) 1.142 (1.013,1.288) 1.057 (0.969,1.123) 1.057 (0.969,1.153) 1.076 (0.940,1.233) 1.033 (0.947,1.126) 1.073 (0.995,1.157) 1.060 (0.967,1.162)	0.786 0.888 0.198 0.941 0.769 0.501 0.672
0.158 0.268 0.359 0.283 0.968 0.283	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.799,1.636) 0.629 (0.326,1.214) 1.057 (0.695,1.608) 1.046 (0.756,1.448) 0.775 (0.516,1.165)		% Obesity Low Middle High % National Basic Livelihood Security Recipient Low Middle High Commet medical needs Low Middle High Other respiratory disease Population density Low		1.088 (0.986,1.192) 1.046 (0.977,1.119) 1.038 (0.984,1.129) 1.142 (1.013,1.288) 1.053 (0.967,1.123) 1.057 (0.969,1.153) 1.076 (0.944,1.233) 1.033 (0.947,1.126) 1.073 (0.945,1.157) 1.060 (0.967,1.162) 0.966 (0.750,1.294)	0.786 0.888 0.198 0.941 0.769 0.501 0.672
.158 .268 .359 .283 .968 .283	0.905 (0.665,1,232) 1.269 (0.875,1,841) 0.643 (0.374,1.104) 0.926 (0.687,1,248) 1.143 (0.798,1,569) 0.629 (0.326,1,214) 1.057 (0.695,1,608) 1.057 (0.516,1.48) 0.775 (0.516,1.46) 1.083 (0.390,3.008) 1.300 (0.952,1,775)		* Obesity Low Middle High * National Basic Livelihood Security Recipient Low Middle High * Unme medical needs Middle High Other respiration density - Low Middle		1.069 (0.986, 1.92) 1.046 (0.977, 1.19) 1.038 (0.954, 1.29) 1.053 (0.967, 1.123) 1.057 (0.969, 1.153) 1.076 (0.940, 1.233) 1.073 (0.965, 1.157) 1.060 (0.967, 1.162) 0.966 (0.750, 1.266)	0.786 0.888 0.198 0.941 0.769 0.501 0.672
.158 .268 .359 .283 .968 .283 .733 .776	0.905 (0.665.1.232) 1.269 (0.675,1.841) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.799,1.636) 0.629 (0.326,1.214) 1.045 (0.326,1.214) 1.045 (0.326,1.214) 1.045 (0.356,1.165) 1.083 (0.390,3.009) 1.300 (0.952,1.775) 0.933 (0.791,1.101)		% Obeaity Low Middle High % National Basic Livelihood Security Recipient Low Middle High % Unmet medical needs Low Middle High Other respiratory disease Population density Low Middle High		1.066 (0.986, 1.92) 1.046 (0.977, 1.19) 1.038 (0.984, 1.29) 1.142 (1.013, 1.288) 1.057 (0.980, 1.133) 1.057 (0.940, 1.233) 1.057 (0.940, 1.233) 1.053 (0.947, 1.126) 1.053 (0.947, 1.126) 1.056 (0.947, 1.126) 0.986 (0.750, 1.296) 1.056 (0.947, 1.737) 1.056 (0.947, 1.737) 1.0	0.786 0.888 0.198 0.941 0.769 0.501 0.672
0.158 0.268 0.359 0.283 0.283 0.283 0.733 0.776	0.905 (0.665,1,232) 1.269 (0.875,1,841) 0.643 (0.374,1.104) 0.926 (0.687,1,248) 1.143 (0.798,1636) 0.629 (0.326,1,214) 1.057 (0.695,1,608) 1.046 (0.756,1,448) 0.775 (0.516,1,165) 1.083 (0.390,3,008) 1.300 (0.952,1,776)		* Obesity Low Middle High National Basic Livelihood Security Recipient Low Middle High * Unmet medical needs Low Middle High Other reparatory disase Population dansity Low Middle High High High High High		1.069 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.954, 1.29) 1.142 (1.013, 1.288) 1.053 (0.987, 1.123) 1.057 (0.989, 1.53) 1.057 (0.940, 1.23) 1.033 (0.947, 1.26) 1.058 (0.947, 1.26) 1.056 (0.947, 1.26) 1.056 (0.947, 1.78) 1.036 (0.979, 1.022) 1.036 (0.979, 1.926) 1.036 (0	0.786 0.888 0.198 0.941 0.769 0.501 0.672 0.639 0.737
.158 .268 .283 .283 .283 .283 .283 .733 .776	0.905 (0.665, 1.232) 1.269 (0.875, 1.841) 0.643 (0.374, 1.104) 1.143 (0.739, 1.836) 0.629 (0.326, 1.244) 1.045 (0.759, 1.848) 0.629 (0.326, 1.244) 1.046 (0.755, 1.448) 0.775 (0.551, 1.485) 1.083 (0.390, 3.008) 1.300 (0.952, 1.775) 0.933 (0.791, 1.101) 0.944 (0.800, 1.115)		% Obesity Low Middle High % National Basic Livelihood Security Recipient Low Middle High % Unmet medical needs Niddle High Other respiratory disease Population density Low Middle High Park accessibility Low		1.066 (0.986, 1.92) 1.046 (0.977, 1.19) 1.038 (0.984, 1.29) 1.142 (1.013, 1.288) 1.053 (0.987, 1.32) 1.057 (0.964, 1.53) 1.076 (0.940, 1.233) 1.076 (0.947, 1.78) 1.076 (0.947, 1.78) 1.056 (0.047, 1.78) 1.056 (0.047, 1.78) 1.056 (0.047, 1.78) 1.056 (0.047, 1.78)	0.786 0.888 0.198 0.941 0.769 0.501 0.672
.158 .268 .283 .283 .283 .283 .733 .776 .184 .192	0.905 (0.665.1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.799,1.636) 0.629 (0.326,1.214) 1.045 (0.756,1.568) 1.046 (0.756,1.568) 1.030 (0.952,1.775) 0.933 (0.731,1.161) 0.934 (0.802,1.155)		% Obeaity Low Middle High % National Basic Livelihood Security Recipient Low Middle High Comer medical needs Low Middle High Other respiratory disease Population density Middle High Park accessibility Low Middle		1.066 (0.986, 1.92) 1.046 (0.977, 1.19) 1.038 (0.987, 1.23) 1.042 (1.013, 1.288) 1.057 (0.986, 1.133) 1.057 (0.986, 1.133) 1.057 (0.986, 1.137) 1.058 (0.987, 1.128) 1.033 (0.947, 1.128) 1.033 (0.947, 1.128) 1.039 (0.947, 1.128) 1.0	0.786 0.888 0.198 0.941 0.769 0.501 0.672 0.639 0.737
1158 2268 359 283 283 283 283 7733 .776 1184 .192	0.905 (0.865,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 1.143 (0.739,1.536) 0.629 (0.326,1.244) 1.143 (0.739,1.536) 0.629 (0.326,1.244) 1.057 (0.695,1.648) 0.775 (0.516,1.165) 1.300 (0.952,1.775) 0.933 (0.791,1.161) 0.944 (0.752,1.610) 1.185 (0.872,1.610) 1.812 (0.683,4.808)		% Obesity Low Middle High % National Basic Livelihood Security Recipient Low Middle High % Unmet medical needs Low Middle High Other reparatory disease Population density Low Middle High Niddle High Middle High Niddle High Scurrent Smokion		1.066 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.954, 1.29) 1.142 (1.013, 1.288) 1.053 (0.947, 1.123) 1.057 (0.949, 1.233) 1.057 (0.949, 1.233) 1.033 (0.947, 1.26) 1.058 (0.947, 1.26) 1.039 (0.978, 1.092) 1.033 (0.978, 1.092)	0.786 0.888 0.198 0.941 0.769 0.501 0.672 0.639 0.737
0.158 0.268 0.283 0.283 0.283 0.283 0.283 0.733 0.776 0.184 0.192	0.905 (0.665,1232) 1269 (0.875,184) 0.643 (0.374,1104) 1.43 (0.799,1386) 0.629 (0.326,1244) 1.045 (0.756,148) 1.046 (0.756,148) 1.046 (0.756,148) 1.046 (0.756,148) 1.030 (0.952,175) 0.933 (0.791,1101) 0.944 (0.800,1115) 1.185 (0.872,1610) 1.812 (0.688,4.808) 0.861 (0.698,1.062)		% Obeaity Low Middle High % National Basic Livelihood Security Recipient Low Middle High % Umer medical needs Niddle High Other respiratory disease Population density Population density Low Middle High Park accessibility Low Middle High Quark accessibility Low Middle Low Middle Low Middle Low		1.086 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.984, 1.29) 1.142 (1.013, 1.288) 1.057 (0.984, 1.23) 1.057 (0.984, 1.53) 1.076 (0.940, 1.233) 1.033 (0.947, 1.26) 1.073 (0.947, 1.26) 1.076 (0.947, 1.276) 1.056 (0.947, 1.78) 1.056 (0.947, 1.78) 1.034 (0.979, 1.92) 1.033 (0.978, 1.92) 1.033 (0.978, 1.92) 1.033 (0.978, 1.92) 1.033 (0.978, 1.92) 1.225 (0.951, 1.579) 1.225 (0.951, 1.579)	0.786 0.888 0.198 0.941 0.769 0.501 0.672 0.639 0.737 0.996 0.190
.158 .268 .359 .283 .968 .283 .773 .184 .192 .331	0.905 (0.665.1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.799,1.636) 0.629 (0.326,1.214) 1.045 (0.756,1.568) 1.046 (0.756,1.568) 1.046 (0.556,1.765) 1.083 (0.390,3.006) 1.300 (0.952,1.775) 0.933 (0.731,1.101) 0.944 (0.800,1.115) 1.812 (0.683,4.808) 0.861 (0.699,1.602) 0.861 (0.699,1.602)		% Obeaity Low Middle High % National Basic Livelihood Security Recipient Low Middle High Cher respiratory disease Population density Low Middle High Park accessibility Low Middle High Park accessibility Low Middle High Cher respiratory disease Population density		1.060 (0.986, 1.182) 1.046 (0.977, 1.192) 1.048 (0.987, 1.123) 1.042 (1.013, 1.288) 1.053 (0.987, 1.123) 1.057 (0.989, 1.53) 1.057 (0.989, 1.557) 1.060 (0.967, 1.123) 1.060 (0.967, 1.162) 1.060 (0.967, 1.162) 1.060 (0.967, 1.162) 1.033 (0.978, 1.082) 1.033 (0.958, 1.182) 1.033 (0.958, 1.182) 1.034 (0.958, 1.182) 1.035 (0.958, 1.182) 1	0.786 0.888 0.198 0.941 0.769 0.501 0.672 0.639 0.737 0.996 0.190 0.637
.158 .268 .359 .283 .968 .283 .776 .184 .192 .331 .022	0.905 (0.665,1.232) 1.269 (0.875,1.841) 0.643 (0.374,1.104) 1.143 (0.739,1.536) 0.629 (0.328,1.214) 1.037 (0.698,1.608) 0.755 (0.516,1.463) 0.755 (0.516,1.463) 0.300 (0.952,1.775) 0.933 (0.791,1.101) 0.944 (0.782,1.610) 1.185 (0.872,1.610) 1.812 (0.683,4.808) 0.861 (0.699,1.062) 1.017 (0.771,1.343) 0.273 (0.986,1.675)		* Obesity Low Middle High * National Basic Livelihood Security Recipient Low Middle High * Unmet medical needs Low Middle High Population density Coher respiratory disease Population density Low Middle High % Current Smoking Low Middle High % Current Smoking Low Middle High		1.066 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.954, 1.29) 1.142 (1.013, 1.288) 1.053 (0.967, 1.123) 1.057 (0.969, 1.53) 1.057 (0.940, 1.233) 1.033 (0.947, 1.26) 1.058 (0.940, 1.233) 1.033 (0.947, 1.126) 1.058 (0.947, 1.26) 1.058 (0.947, 1.26) 1.056 (0.947, 1.26) 1.056 (0.947, 1.26) 1.033 (0.927, 1.02) 1.033 (0.978, 1.029) 1.033 (0.978, 1.029) 1.023 (0.958, 1.157) 1.052 (0.958, 1.157) 1.054 (0.958, 1.169)	0.786 0.888 0.198 0.941 0.769 0.639 0.639 0.737 0.996 0.190
1158 (288) (359) (283) (968) (283) (773) (776) (184) (192) (331) (022)	0.905 (0.665,1232) 1.269 (0.875,184) 0.643 (0.374,1104) 1.143 (0.799,1.536) 0.629 (0.326,1244) 1.045 (0.756,1.448) 1.046 (0.756,1.448) 0.075 (0.1516,1.165) 1.083 (0.390,3.006) 1.083 (0.390,3.006) 1.083 (0.390,3.006) 1.083 (0.390,3.006) 1.083 (0.683,4.408) 0.861 (0.683,4.408) 0.861 (0.683,4.608) 0.861 (0.683,4.608) 1.017 (0.771,1.343) 1.273 (0.3968,1.675)		% Obesity Low Middle High % National Basic Livelinod Security Recipient Low Middle High % Unmet medical needs Low Middle High Other respiratory disease Population density Population density Low Middle High Park accessibility Low Middle High Com Kow Middle High Souther Smoking Low Middle High Souther Smoking Low		1.066 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.987, 1.23) 1.042 (1.013, 1.289) 1.057 (0.969, 1.123) 1.057 (0.969, 1.123) 1.057 (0.969, 1.123) 1.058 (0.967, 1.126) 1.058 (0.967, 1.126) 1.056 (0.967, 1.126) 1.056 (0.967, 1.296) 1.056 (0.967, 1.296) 1.056 (0.977, 1.282) 1.033 (0.977, 1.082) 1.033 (0.977, 1.082) 1.033 (0.977, 1.082) 1.033 (0.977, 1.082) 1.033 (0.977, 1.082) 1.033 (0.977, 1.082) 1.033 (0.978, 1.082) 1.033 (0.978, 1.082) 1.023 (0.954, 1.082) 1.052 (0.954, 1.162) 1.054 (0.958, 1.162)	0.786 0.888 0.198 0.941 0.769 0.501 0.672 0.639 0.190 0.996 0.190
0.158 0.268 0.283 0.968 0.283 0.733 0.776 0.184 0.192 0.331 0.022	0.905 (0.665, 1.232) 1.269 (0.875, 1.841) 0.643 (0.374, 1.104) 1.143 (0.739, 1.536) 0.629 (0.326, 1.244) 1.143 (0.739, 1.536) 0.629 (0.326, 1.244) 1.057 (0.695, 1.608) 1.300 (0.952, 1.775) 0.933 (0.739, 1.161) 0.944 (0.800, 1.15) 1.815 (0.872, 1.610) 1.815 (0.872, 1.610) 1.812 (0.683, 4.808) 0.861 (0.698, 1.062) 1.017 (0.771, 1.343) 1.273 (0.968, 1.675)		* Obesity Low Middle High * National Basic Livelihood Security Recipient Low Middle High * Unmet medical needs Low Middle High Other reparatory disease Other reparatory disease Addle High High Widdle High % Current Smoking Low Middle High * Obesity Low		1.066 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.984, 1.29) 1.142 (1.013, 1.288) 1.057 (0.894, 1.32) 1.057 (0.894, 1.32) 1.057 (0.994, 1.33) 1.033 (0.947, 1.126) 1.078 (0.946, 1.157) 1.060 (0.957, 1.02) 1.036 (0.957, 1.02) 1.036 (0.957, 1.02) 1.039 (0.957, 1.02) 1.059 (0.951, 1.12) 1.050 (0.954, 1.12)	0.786 0.888 0.198 0.941 0.769 0.501 0.672 0.639 0.737 0.996 0.190
.158 .289 .283 .283 .283 .283 .283 .283 .283 .283	0.905 (0.665,1.232) 1.269 (0.875,1.84) 0.643 (0.374,1.104) 0.926 (0.867,1.248) 1.143 (0.799,1.536) 0.629 (0.326,1.214) 1.037 (0.696,1.669) 0.468 (0.756,1.448) 0.775 (0.516,1.165) 1.030 (0.952,1.775) 0.933 (0.791,1.101) 0.944 (0.800,1.115) 1.185 (0.872,1.610) 1.185 (0.872,1.610) 1.181 (0.800,1.115) 1.812 (0.683,1.828) 0.861 (0.999,1.062) 1.017 (0.771,1.343) 1.273 (0.988,1.675) 1.020 (0.883,1.221)		* Obesity Low Middle Low Middle High Notational Basic Livelihood Security Recipient Low Middle High Sumet medical needs High Other respiration density Duther respiration density Low Middle High Other respiration density Low Middle High Corrent Smoking Low High Scurrent Smoking Low High Low Low High Low Low High Low Low High Low		1.046 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.984, 1.29) 1.142 (1.013, 1.288) 1.053 (0.947, 1.23) 1.057 (0.946, 1.153) 1.076 (0.940, 1.233) 1.076 (0.947, 1.78) 1.076 (0.947, 1.78) 1.076 (0.947, 1.78) 1.076 (0.947, 1.78) 1.033	0.786 0.888 0.198 0.941 0.769 0.501 0.639 0.737 0.996 0.190 0.637 0.608
.158 .268 .283 .968 .283 .733 .776 .184 .192 .331 .022 .405 .101	0.905 (0.665,1232) 1.269 (0.875,184) 0.643 (0.374,1104) 1.143 (0.799,1.536) 0.629 (0.326,124) 1.045 (0.756,1469) 1.046 (0.756,1469) 1.046 (0.756,1469) 0.775 (0.516,1165) 1.083 (0.390,3.006) 1.083 (0.390,3.006) 1.083 (0.390,3.006) 1.812 (0.683,4.808) 0.681 (0.683,4.808) 1.017 (0.771,1.343) 1.273 (0.968,1.675) 1.042 (0.883,1.467) 0.743 (0.494,1.031)		% Obesity Low Middle High % National Basic Livelihood Security Recipient Low Middle High % Unter medical needs Low Middle High Other respiratory disease Population density Low Middle High Park accessibility Low Middle High % Current Smoking Low Middle High % Obesity Low Middle High % Obesity Low Middle High % Obesity Low Middle High		1.046 (0.986, 1.92) 1.046 (0.977, 1.19) 1.038 (0.987, 1.23) 1.042 (1.013, 1.288) 1.057 (0.969, 1.133) 1.057 (0.969, 1.133) 1.057 (0.969, 1.133) 1.058 (0.947, 1.126) 1.058 (0.948, 1.126) 1.0	0.786 0.888 0.9941 0.691 0.679 0.769 0.637 0.996 0.190 0.637 0.637 0.637
.158 .268 .283 .283 .283 .283 .283 .283 .283 .28	0.905 (0.665, 1.232) 1.269 (0.875, 1.84) 0.643 (0.374, 1.104) 1.143 (0.739, 1.536) 0.629 (0.326, 1.244) 1.143 (0.739, 1.536) 0.629 (0.326, 1.244) 1.057 (0.695, 1.608) 1.300 (0.952, 1.775) 0.933 (0.791, 1.161) 0.946 (0.756, 1.448) 1.136 (0.872, 1.610) 1.812 (0.683, 4.808) 0.861 (0.692, 1.027, 1.143) 1.1273 (0.968, 1.675) 1.002 (0.823, 1.221) 1.142 (0.889, 1.467) 0.713 (0.494, 1.031)		% Obesity           Low           High           Yelligh           % National Basic Livelihood Security Recipient Low           Middle           High           % Unmer medical needs           Low           Middle           High           % Unmer medical needs           Low           Middle           High           Other repairation density           Low           Middle           High           % Current Smoking           Low           Middle           High           % Obesity           Low           Middle           High           % Obesity           Low           Middle           High           % Obesity           Low           High Security Recipient           Low		1.066 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.984, 1.29) 1.142 (1.013, 1.288) 1.057 (0.989, 1.123) 1.057 (0.989, 1.123) 1.057 (0.989, 1.123) 1.033 (0.947, 1.126) 1.078 (0.986, 1.157) 1.060 (0.957, 1.162) 0.986 (0.750, 1.286) 1.054 (0.937, 1.162) 1.033 (0.947, 1.178) 1.034 (0.957, 1.162) 1.034 (0.957, 1.162) 1.035 (0.957, 1.162) 1.035 (0.957, 1.162) 1.054 (0.958, 1.162) 1.054 (0.958, 1.162) 1.056 (0.982, 1.162) 1.	0.786 0.888 0.941 0.769 0.631 0.639 0.737 0.996 0.190 0.637 0.608 0.424 0.943
.158 .268 .359 .283 .283 .283 .773 .184 .192 .331 .022 .405 .101	0.905 (0.665, 1.232) 1.269 (0.875, 1.841) 0.643 (0.374, 1.104) 1.143 (0.799, 1.836) 0.629 (0.326, 1.244) 1.143 (0.799, 1.836) 0.629 (0.326, 1.244) 1.046 (0.755, 1.448) 0.775 (0.516, 1.165) 1.083 (0.390, 3.008) 1.030 (0.955, 1.748) 0.333 (0.791, 1.101) 0.944 (0.800, 1.115) 1.185 (0.872, 1.610) 1.812 (0.684, 3.608) 0.861 (0.699, 1.062) 1.017 (0.771, 1.343) 1.273 (0.968, 1.675) 1.144 (0.088, 1.467) 1.142 (0.883, 1.421) 1.142 (0.883, 1.421) 1.142 (0.883, 1.421) 0.713 (0.494, 1.031) 0.983 (0.811, 1.191) 0.288 (0.877, 1.309)		% Obesity         Low         Middle         High         % National Basic Livelihood Security Recipient         Low         Middle         High         % Unmer medical needs         High         % Unmer medical needs         High         Other respiratory disease         Population density         Low         Middle         High         Cov         Middle         High         South Cove         Middle         Uow         Middle         High         % Current Smoking         Low         Middle         High         % Obesity         Low         Middle         High         % Obesity         Low         Middle         High		1.066 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.984, 1.29) 1.142 (1.013, 1.288) 1.053 (0.947, 1.28) 1.057 (0.940, 1.233) 1.057 (0.940, 1.233) 1.058 (0.947, 1.28) 1.058 (0.947, 1.18) 1.225 (0.951, 1.59) 1.225 (0.951, 1.59) 1.225 (0.951, 1.59) 1.058 (0.958, 1.69) 1.058 (0.958, 1.69) 1.056 (0.948, 1.12) 1.050 (0.948, 1.12) 1.050 (0.948, 1.12) 1.050 (0.948, 1.12) 1.051	0.786 0.888 0.198 0.591 0.672 0.637 0.996 0.637 0.608 0.424 0.445
.158 .268 .359 .283 .968 .283 .776 .184 .192 .331 .022 .405 .101 .765 .923	0.905 (0.665, 1.232) 1.269 (0.875, 1.641) 0.643 (0.374, 1.104) 1.143 (0.739, 1.636) 0.629 (0.326, 1.248) 1.143 (0.739, 1.636) 0.629 (0.326, 1.248) 1.037 (0.955, 1.648) 0.775 (0.516, 1.165) 1.046 (0.755, 1.448) 0.775 (0.516, 1.165) 1.030 (0.952, 1.775) 0.933 (0.791, 1.101) 0.944 (0.800, 1.151) 1.812 (0.883, 4.808) 0.881 (0.689, 1.062) 1.301 (0.692, 1.621) 1.812 (0.883, 4.808) 0.881 (0.688, 1.675) 1.017 (0.771, 1.343) 1.273 (0.968, 1.675) 1.022 (0.823, 1.221) 1.142 (0.832, 1.221) 1.042 (0.832, 1.221) 1.042 (0.832, 1.221) 1.042 (0.837, 1.309) 0.983 (0.811, 1.191) 1.028 (0.807, 1.309)		% Obesity Low Middle High S National Basic Livelihood Security Recipient Low Middle High S Umer medical needs Low Middle High Other repiratory disase Population dansity Low Middle High S Current Smoking Low Middle High S Obesity Low Middle High S Obesity High S Obesity Low Middle High S Obesity Low Middle High S Obesity Low Middle High S Obesity Low Middle High S Obesity Low Middle High S Obesity S Obesity S Obesity S Obesity High S Obesity S Obesity S Obesity High S Obesity S Obesity S Obesity High S Obesity S Obesity S Obesity High S Obesity S Obesity S Obesity S Obesity High S Obesity S Obesit		1.086 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.987, 1.123) 1.042 (1.013, 1.288) 1.057 (0.989, 1.132) 1.057 (0.949, 1.132) 1.057 (0.949, 1.132) 1.058 (0.947, 1.126) 1.078 (0.949, 1.137) 1.060 (0.947, 1.126) 1.038 (0.947, 1.126) 1.054 (0.958, 1.162) 1.054 (0.958, 1.162) 1.056 (0.948, 1.120) 1.056 (0.948, 1.120) 1.051 (0.948, 1.127) 1.051 (0.948, 1.127)	0.786 0.888 0.941 0.769 0.501 0.672 0.639 0.737 0.996 0.190 0.637 0.608 0.424 0.943
158 268 359 283 968 283 733 776 184 192 331 022 405 101 765 923	0.905 (0.665,1.232) 1.269 (0.875,1.84) 0.643 (0.374,1.104) 0.926 (0.687,1.248) 1.143 (0.739,1.536) 0.629 (0.328,1.214) 1.037 (0.695,1.608) 1.046 (0.756,1.448) 0.775 (0.516,1.165) 1.030 (0.952,1.775) 0.933 (0.390,3.006) 1.300 (0.952,1.775) 0.933 (0.391,1.101) 0.944 (0.800,1.157) 1.185 (0.872,1.610) 1.812 (0.683,4.808) 0.861 (0.699,1.062) 1.017 (0.771,1.343) 0.861 (0.699,1.062) 1.071 (0.771,1.343) 0.861 (0.691,1.021) 1.422 (0.883,1.467) 0.733 (0.494,1.031) 0.983 (0.811,1.101) 0.983 (0.811,1.101)		% Obesity         Low         Middle         High         % National Basic Livelihood Security Recipient         Low         Middle         High         % Unmet medical needs         Low         Middle         High         % Unmet medical needs         Low         Middle         High         Other respiratory disease         Population density         Low         Middle         High         Cow         Middle         Low         Middle         High         % Obesity         Low         Middle         High         % Obesity         Low         Middle         High         % National Basic Livelihood Security Recipient         Low         Middle         High         % Unmet medical needs		1.046 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.984, 1.29) 1.142 (1.013, 1.288) 1.053 (0.947, 1.23) 1.057 (0.949, 1.233) 1.057 (0.949, 1.233) 1.073 (0.947, 1.28) 1.073 (0.947, 1.28) 1.073 (0.947, 1.28) 1.058 (0.947, 1.28) 1.058 (0.947, 1.28) 1.033 (0.947, 1.28) 1.033 (0.947, 1.28) 1.033 (0.947, 1.28) 1.033 (0.947, 1.09) 1.033 (0.928, 1.59) 1.033 (0.928, 1.59) 1.052 (0.948, 1.29) 1.052 (0.948, 1.129) 1.052 (0.948, 1.129) 1.054 (0.958, 1.169) 1.056 (0.947, 1.78) 1.056 (0.947, 1.78) 1.056 (0.948, 1.29) 1.056 (0.948, 1.129) 1.056 (0.948, 1.12	0.786 0.888 0.198 0.941 0.769 0.639 0.737 0.996 0.190 0.637 0.608 0.424 0.843 0.813
158 268 359 263 968 283 733 776 184 192 331 192 331 022 405 101 765 923	0.905 (0.665, 1.232) 1.269 (0.875, 1.841) 0.643 (0.374, 1.104) 1.143 (0.739, 1.836) 0.629 (0.326, 1.244) 1.143 (0.739, 1.836) 0.629 (0.326, 1.244) 1.046 (0.755 (0.695, 1.648) 0.775 (0.695, 1.648) 1.046 (0.755, 1.448) 0.775 (0.516, 1.165) 1.300 (0.952, 1.750) 0.933 (0.791, 1.101) 0.944 (0.800, 1.115) 1.185 (0.872, 1.670) 1.812 (0.684, 4.808) 0.861 (0.699, 1.062) 1.017 (0.771, 1.343) 1.273 (0.968, 1.675) 1.002 (0.823, 1.221) 1.142 (0.888, 1.467) 0.713 (0.494, 1.031) 0.983 (0.517, 1.539) 0.959 (0.597, 1.539)		% Obesity           Low           Middle           High           % National Basic Livelihood Security Recipient           Low           Middle           High           % Unmet medical needs           Middle           High           % Unmet medical needs           Middle           High           Other respiratory disease           Population density           Low           Middle           High           Scurrent Smoking           Low           High           % Obesity           Low           High           % Obesity           Low           High           % National Basic Livelihood Security Recipient           Low           Middle           High		1.066 (0.986, 1.92) 1.046 (0.977, 1.19) 1.038 (0.987, 1.23) 1.042 (1.013, 1.288) 1.052 (0.947, 1.23) 1.076 (0.940, 1.233) 1.076 (0.940, 1.233) 1.076 (0.947, 1.26) 1.076 (0.947, 1.26) 1.076 (0.947, 1.26) 1.076 (0.947, 1.26) 1.056 (0.947, 1.26) 1.056 (0.947, 1.26) 1.056 (0.947, 1.26) 1.033 (0.947, 1.26) 1.052 (0.948, 1.162) 1.052 (0.948, 1.162) 1.056 (0.947, 1.160) 1.050 (0.948, 1.162) 1.050 (0.948, 1.16	0.786 0.888 0.198 0.591 0.501 0.639 0.737 0.639 0.190 0.190 0.637 0.638 0.424 0.943 0.445 0.813
158 268 359 283 968 283 733 776 184 192 3311 022 405 101 765 923 004	0.905 (0.665, 1.232) 1.269 (0.875, 1.841) 0.643 (0.374, 1.104) 1.143 (0.739, 1.636) 0.629 (0.326, 1.244) 1.143 (0.739, 1.636) 0.629 (0.326, 1.244) 1.057 (0.059, 1.608) 1.300 (0.952, 1.755) 0.633 (0.390, 3.006) 1.300 (0.952, 1.775) 0.933 (0.791, 1.101) 0.944 (0.800, 1.155) 1.315 (0.372, 1.610) 1.812 (0.683, 4.808) 0.861 (0.689, 1.062) 1.3145 (0.872, 1.610) 1.812 (0.683, 4.808) 0.713 (0.494, 1.031) 0.983 (0.811, 1.191) 1.028 (0.807, 1.309) 0.956 (0.597, 1.539) 0.956 (0.597, 1.539) 0.956 (0.597, 1.539)		% Obesity           Low           Middle           High           % National Basic Livelihood Security Recipient           Low           Middle           High           % Unmet medical needs           Low           Middle           High           Other repiratory disease           Other repiratory disease           Middle           High           Cow           Middle           High           Cow           Middle           High           Cow           Middle           High           Sobesity           Low           Middle           High           % Obesity           Low           Middle           High           % National Basic Livelihood Security Recipient           Low           Middle           High           Middle           High		1.066 (0.986, 1.182) 1.046 (0.977, 1.19) 1.038 (0.987, 1.123) 1.058 (0.987, 1.23) 1.057 (0.989, 1.133) 1.057 (0.989, 1.133) 1.057 (0.989, 1.133) 1.057 (0.989, 1.133) 1.058 (0.987, 1.128) 1.058 (0.988, 1.129) 1.056 (0.988, 1.129) 1.056 (0.988, 1.129) 1.056 (0.988, 1.129) 1.051 (0.988, 1.127) 1.051 (0.988, 1.127) 1.	0.786 0.888 0.981 0.941 0.769 0.737 0.996 0.737 0.996 0.637 0.608 0.424 0.943 0.445 0.813

**Fig. 5** Effect modifications by district-level indicators in the NO<sub>2</sub> (lag 0–5)-respiratory mortality risk in the individuals aged 0–59 y and aged 80 y or older. *P*-values indicate the statistical test results on the effect modification (i.e. magnitude of differences in estimates for middle or high-levels compared to low-level; not for the hypothesis that OR is one). %: proportion. NO<sub>2</sub>: nitrogen dioxide. Odd ratios (ORs) for a 0.01 ppm (10 ppb) increase in NO<sub>2</sub>

**Table 2** Excess death fractions and YLL (Year of Life Lost from mortality) attributable to ambient short-term exposure to NO<sub>2</sub> (lag 0–5) for respiratory mortalities. NO<sub>2</sub>: nitrogen dioxide

Cause of death		All-range of PM <sub>2.5</sub>		WHO guideline compliance		
	Age group	Excess deaths (%)	Excess YLL (years)	Excess deaths (%)	Excess YLL (years)	
Respiratory disease	Total	4.13 (0.87–7.4)	93,851.63 (19,779.11–167,983.69)	3.06 (0.65–5.44)	70,137.1 (14,924.97–124,721.11)	
	0-59 years	-0.86 (-18.39-14.72)	–19,527.33 (–418,028.33–334,285.78)	-0.77 (-14.43-10.63)	-17,708.82 (-330,805.7-243,721.42)	
	60–69 years	2.44 (-10.09-14.01)	55,505.05 (–229,293.12–317,974.14)	1.75 (–7.76–10.13)	40,197.35 (–177,779.19–232,242.61)	
	70–79 years	-0.18 (-7.12-6.56)	-4045.92 (-161,835.04-148961.15)	-0.16 (-5.43-4.84)	-3555.95 (-124,559.71-110,827.91)	
	80 y and older	6.38 (2.36–10.37)	144,936.7 (53,639.82–235,570.93)	4.7 (1.76–7.57)	107,715.31 (40,326.26–173,614.0)	
Pneumonia	Total	3.25 (–1.06–7.51)	42,261.11 (–13,775.96–97,815.11)	2.4 (-0.79-5.51)	31,446.79 (–10,397.91–72,265.19)	
	0–59 years	0.8 (-22.4-20.45)	10,366.55 (–291,683.25–266,162.39)	0.38 (–17.72–14.53)	5001.6 (–232,121.31–190,382.81)	
	60–69 years	-4.6 (-24.91-13.15)	–59,917.22 (–324,379.29–171,133.55)	3.65 (19.839.51)	-47,859.08 (-259,737.78-124,663.67)	
	70–79 years	-0.08 (-9.78-9.1)	–1081.76 (,318.91–118,431.39)	0.1 (7.56.65)	–1355.59 (–98,207.76–87,150.48)	
	80 y and older	5.16 (0.01–10.22)	67,144.59 (127.83–133,002.25)	3.8 (0.01–7.45)	49,743.69 (96.23–97,599.13)	
Chronic lower respiratory diseases	Total	5.29 (–1.99–12.31)	24,599.6 (–9280.38–57,233.47)	3.74 (–1.45–8.61)	17,634.43 (–6812.12–40,567.73)	
	0–59 years	-10.83 (-71.44-30.64)	-50,521.6 (-333,313.62-142,297.7)	-9.22 (-61.22-20.51)	–43,598.38 (–289,370.71–96,513.75)	
	60-69 years	-2.17 (-30.78-21.26)	–10,150.65 (–143,404.53–98,794.91)	-1.88 (-23.93-14.56)	-8872.69 (-112,947.0-68525.47)	
	70–79 years	-0.77 (-15.82-12.87)	–3606.25 (–73,670.91–59,853.0)	-0.65 (-11.86-8.99)	–3066.53 (–55,941.99–42,366.33)	
	80 y and older	9.89 (0.87–18.41)	45,973.81 (4030.89–85,569.0)	6.93 (0.62–12.69)	32,627.65 (2938.14–59,761.22)	
Other respiratory diseases	Total	5.59 (–1.63–12.55)	28,089.73 (–8171.77–63,042.9)	4.28 (-1.28-9.5)	21,697.38 (–6459.24–48,134.97)	
	0–59 years	-2.04(-37.99-25.92)	-10,262.43 (-191,068.05-130197.1)	-2.1 (-32.56-18.99)	-10,590.46 (-164,773.03-96204.4)	
	60-69 years	15.27(-5.76-32.91)	76,697.6 (–28,953.94–165,229.39)	11.31 (-4.56-23.69)	57,318.75 (–23,117.37–120,027.21)	
	70–79 years	0.16(-14.33-13.35)	801.43 (–72,059.09–67063.9)	0.03 (11.610.09)	172.12 (–58,739.01–51104.78)	
	80 y and older	6.92(-2.89-16.15)	34,780.85 (–14,535.22–81,143.28)	5.27 (–2.28–12.12)	26,711.78 (–11,524.58–61,410.34)	

each study. The three studies we mentioned above have been performed from 1990–1997 in 30 European cities [38], 1997–2007 in Santiago [9], and 1998–2001 in Hong Kong [42]. However, a recent multi-country study involving Jiangsu (China), California (the United States), Central-southern Italy, and Germany from 2015–2019 reported no NO<sub>2</sub> risk on mortality or substantially small risk estimates in people aged less than 75 y, and the association between NO<sub>2</sub> and mortality became more pronounced after 75 y in all countries [30]. These results are generally consistent with our findings with the same study period: 2015–2019. Of course, although it should be interpreted with extreme caution because there might be a lot of potential confounders, we cautiously suggest that the concepts of high-risk populations regarding "the elderly" might need to be re-discussed in-depth from the perspective of health risks related to air pollution.

In addition, we found that the association between  $NO_2$  and mortality for other respiratory disease was more pronounced in people aged 60–69, although the

statistical evidence was insufficient. According to the ICD-10 category, the other respiratory disease mortality we used included mortality for influenza, acute respiratory infections, etc. Previous animal and human studies have identified that NO<sub>2</sub> inhalation negatively affects these diseases [5, 47]. Although this study is limited in providing exact evidence, previous studies might suggest some hypotheses: existing studies revealed that individuals with early COPD were related to an increased risk of acute respiratory hospitalization and early death [13, 44]. In addition, based on the Korean National Health and Nutrition Examination Survey in 2018 [23], the current smoking rate was much higher in individuals aged 60-69 (14.9%) than in individuals aged 70 y or older (6.6%). Thus, we cautiously surmised that relatively young elderly with risk factors for severe acute respiratory diseases, like influenza, could be more vulnerable to respiratory mortality risks related to NO<sub>2</sub> compared to other older age groups because of poorer pulmonary health conditions and health behaviors, although more studies are required.

Our findings related to effect modification by districtlevel characteristics also should be interpreted carefully. Although the statistical evidence was relatively weak, we found areas with low population density showed a higher NO<sub>2</sub>-related respiratory mortality risk in total respiratory and pneumonia deaths. Along with a high average age of people living in low-density areas (i.e., rural areas) [23], we conjecture that poorer accessibility to medical facilities in low-density areas could be associated with a higher vulnerability to environmental stressors, which was addressed in a previous study [26]. Further, although the finding was also statistically weak, we observed that areas with the highest proportion of Basic Livelihood Security Recipient needs generally exhibited the highest NO<sub>2</sub>-respiratory mortality risk, based on the point estimates. However, although the statistical evidence was substantially weak, areas with a low proportion of Unmet medical needs generally showed a higher NO<sub>2</sub>-respiratory mortality risk compared to areas with a high proportion of Unmet medical needs, especially for pneumonia death. Although this study could provide limited evidence, we carefully conjecture that there might be an ecological bias. In South Korea, the proportion of Unmet medical needs was generally lower in urban cities, although some metropolitan areas (Ulsan and Incheon metropolitan cities) and more urbanized regions (Gyeonggi and Gyeongnam provinces) had a higher proportion of Unmet medical needs [23] due to their large population size. In other words, the reason for the higher NO<sub>2</sub>-related respiratory death in areas with a low proportion of Unmet medical needs might be confounded by the urbanicity level; however, further studies are required. In addition, we found that the proportion of National Basic Livelihood Security Recipients modified the NO<sub>2</sub>-respiratory mortality risk in individuals aged 80 or older, especially related to pneumonia death [23]. Several studies have reported that lower socioeconomic status and poorer health behaviors are closely linked to a higher risk of severe respiratory diseases [2, 27, 36]. Thus, although ecological bias from the district-level data could be considered, our findings could suggest that improving community-level socioeconomic status can mitigate respiratory deaths related to NO<sub>2</sub>, especially in "older seniors" (aged 80 y or older) who likely have lower immunity than other younger groups [46].

In addition, our results on the excess respiratory deaths and YLL attributable to short-term NO<sub>2</sub> provide important implications for public health and environmental policies. We found that the excess respiratory mortality fraction attributable to NO<sub>2</sub> related to non-compliance with the current WHO air quality guidelines (daily average NO<sub>2</sub> > 25 µg/m<sup>3</sup>) accounted for over 60% of the total excess mortality due to NO<sub>2</sub>. It indicates the necessity and social benefits of stricter air quality standards regarding NO<sub>2</sub> in South Korea, especially, given the current air quality guidelines of South Korea (0.06 ppm [~110 µg/ m<sup>3</sup>] for 24-h average NO<sub>2</sub>) that are much higher than the WHO guidelines.

Several limitations should be acknowledged. First, we adopted a time-stratified case-crossover design to control confounders that did not substantially change within a month. However, unmeasured short-term time-dependent confounders, such as daily high-risk activities and smoking, etc., might affect our risk estimates. Second, because the national mortality data of this study provided only district-level residential addresses at death (the median size of districts in South Korea: 397 km<sup>2</sup>, which is around 1.7 times larger than the median size of the US zip code areas), thus exposure misclassification could exist. Third, we could not address more specific respiratory diseases, because of the limited data availability. In particular, we were limited in addressing more detailed causes of respiratory death, like asthma, influenza, and COPD, which could be acute, severe, and related to NO<sub>2</sub>. Lastly, due to the insufficient sample size of each specific category, our risk estimates regarding subgroups were statistically weak in general, except estimates for those aged 80 y or older. Many previous epidemiological journals did not recommend using the P-value of the criteria of the significance [18] because the P-value depends on the sample size and most epidemiological studies were based on observational studies without planned samples to test the primary hypothesis. However, because the P-value and 95% confidence interval could provide evidence for the reliability of the association and possibilities of sampling and information errors, our results should be carefully interpreted when the corresponding statistical evidence is weak. In addition, our results for the total population and people aged 80 years or older (with strong statistical evidence) could provide more reliable evidence on the association between  $NO_2$  and respiratory mortality, along with high-risk populations.

Nonetheless, this study has several strengths. First, with high-accuracy machine learning exposure modeling, this study assessed the nationwide association between short-term exposure to outdoor  $NO_2$  and respiratory mortality in South Korea. Second, by stratified and interaction analyses, we examined the heterogeneous association between  $NO_2$  and respiratory mortality by age group, cause of death, sex, and regional characteristics and suggested specific high-risk populations. Our findings provide important evidence for more targeted action plans to reduce the health impacts of  $NO_2$ . Third, by estimating the excess mortality burden attributable to non-compliance with the WHO air quality guidelines, this study suggests the social benefits and justification for establishing more stringent  $NO_2$  air quality standards.

#### Conclusion

In summary, we assessed the nationwide association between short-term ambient  $NO_2$  and respiratory mortality in South Korea and provided evidence regarding high-risk populations. This study also provides findings that might indicate the latent benefits of stricter  $NO_2$  air quality guidelines and potential effect modifications by individual and community-level characteristics that could provide partial evidence for more effective public health resource mobilization.

#### Supplementary Information

The online version contains supplementary material available at https://doi. org/10.1186/s12889-024-21048-w.

Supplementary Material 1.

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#### Authors' contributions

Contributions Seoyeong Ahn: Formal analysis, Data curation, Visualization, Writing – Original draft Hyewon Yun: Formal analysis, Data curation, Visualization, Writing – Original draft Sooyoung Kim: Formal analysis, Data curation, Visualization Yejin Kim: Data curation, Writing – Original draft Jieun Oh, Hyemin Jang: Data curation, Writing – review & editing Sojin Ahn: Writing – review & editing Cinoo Kang, Ayoung Kim, Dohoon Kwon, Jinah Park, Insung Song, Jeongmin Moon, Jieun Min, Ejin Kim: Data curation Ho Kim: Writing – review & editing, Funding acquisition. Whanhee Lee: Conceptualization, Methodology, Investigation, Supervision, Writing – Original draft, Funding acquisition.

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#### Data availability

The data of this study can be provided upon request to the corresponding authors.

#### Declarations

#### Ethics approval and consent to participate

This study was approved by the Institutional Review Board (IRB) of Pusan National University (Review Exemption; IRB number: 2024\_196\_HR). The IRB approval process also waived the requirement for informed patient participation consent because this study used secondary and publicly available data (https://mdis.kostat.go.kr/index.do). The data of this study did not include any information related to personal identification.

#### **Consent for publication**

Not applicable.

#### **Competing interests**

The authors declare no competing interests.

#### Author details

<sup>1</sup>Graduate School of Data Science, Pusan National University, Busan, South Korea. <sup>2</sup>Department of Information Convergence Engineering, College of Information and Biomedical Engineering, Pusan National University, Yangsan, South Korea. <sup>3</sup>Department of Public Health Science, Graduate School of Public Health, Seoul National University, Seoul, South Korea. <sup>4</sup>Institute of Health and Environment, Graduate School of Public Health, Seoul National University, Seoul, South Korea. <sup>5</sup>School of Biomedical Convergence Engineering, College of Information and Biomedical Engineering, Pusan National University, 49-Budandaehak-Ro, Yangsan, Gyeongsangnam-do, South Korea. <sup>6</sup>Research and Management Center for Health Risk of Particulate Matter, Seoul, South Korea.

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