Supplementary Table S1. Detection frequency of $PM_{2.5}$ components

Components	Detection frequency (%)
Carbonaceous components	
OC	100.00
EC	100.00
Water-soluble inorganic ions	
Ca^{2+}	95.32
Cl^{-}	100.00
K^{+}	100.00
NO^{3-}	100.00
Mg^{2+}	82.46
Na^{+}	100.00
NH^{4+}	100.00
$SO4^{2-}$	92.30
Elemental components	
Ba	100.00
Ca	100.00
Cr	98.56
Cu	95.74
Fe	100.00
K	100.00
Mn	100.00
Ni	95.94
Pb	100.00
Se	99.04
Ti	100.00
Tl	95.19
V	93.67
Zn	100.00

Note. OC, organic carbon; EC, elemental carbon; Ca^{2+}, calcium ion; Cl^{-}, chlorine ion; Mg^{2+}, magnesium ion; Na^{+}, sodium ion; K^{+}, potassium ion; NH_4^{+}, ammonium ion; SO_4^{2-}, sulfate ion; NO_3^{-}, nitrate ion; Ba, barium; Ca, calcium; Cr, chromium; Cu, copper; Fe, ferrum; Mn, manganese; K, potassium; Ni, nickel; Pb, lead; Se, selenium; Zn, zinc; V, vanadium; Ti, titanium; Tl, thallium.

Supplementary Table S2. Characteristics of study participants in different samples

Characteristic	*n* = 2045	*n* = 1454	*P* value
Gender (*N*, %)			0.84
male	1,011 (49.44)	713 (49.04)	
female	1,034 (50.56)	741 (50.96)	
Age (Mean ± SD)	65.21 ±13.47	65.26 ±13.47	0.91
Education (*N*, %)			0.55
primary school degree or less	693 (33.89)	478 (32.87)	
middle/high school degree	1,031 (50.42)	769 (52.89)	
college degree or above	295 (14.43)	207 (14.24)	
BMI (kg/m^2,Mean ± SD)	25.71 ± 3.77	25.68 ±3.59	0.82
Current Smoking (*N*, %)			0.94
yes	394 (19.27)	286 (19.67)	
no	1,626 (79.51)	1,168 (80.33)	
Drinking (*N*, %)			0.48
yes	351 (17.16)	267 (18.36)	
no	1,669 (81.61)	1187 (81.64)	

Note. Continuous variables were compared using t-test, and categorical variables were compared using Chi-square test. "*" indicates $P < 0.05$. N, sample size; SD, standard deviation; BMI, body mass index.

Supplementary Table S3. The concentrations of $PM_{2.5}$ components across different cities

Components	Beijing	Tianjin	Shijiazhuang	Baoding	Xionganxinqu	Langfang	Taiyuan	Jinan	Anyang
$PM_{2.5}$	22.57 (52.82)	63.80 (52.00)	93.08 (38.43)	75.18 (29.71)	70.16 (36.21)	28.82 (0.01)	110.43 (77.63)	79.95 (50.03)	75.71 (0.76)
OC	2.77 (6.00)	9.06 (5.18)	11.89 (3.02)	27.75 (13.11)	31.19 (5.40)	3.88 (1.06)	19.11 (7.19)	5.48 (2.55)	0.00 (0.00)
EC	1.66 (1.76)	2.22 (1.37)	13.44 (7.68)	23.16 (3.96)	0.00 (0.00)	0.96 (0.51)	17.13 (29.27)	2.80 (1.46)	2.58 (0.38)
Ca^{2+}	0.27 (0.24)	0.62 (1.08)	3.65 (0.92)	0.00 (0.21)	0.75 (0.50)	0.17 (0.10)	0.68 (0.10)	12.87 (2.53)	4.26 (0.60)
Cl^-	0.97 (2.06)	2.91 (2.20)	2.34 (1.39)	4.18 (1.83)	12.42 (8.17)	0.28 (0.28)	4.30 (1.34)	2.41 (0.55)	0.00 (2.16)
K^+	0.26 (0.38)	1.01 (0.38)	0.25 (0.23)	1.34 (0.61)	0.58 (0.56)	0.46 (7.07)	0.99 (0.60)	2.85 (1.22)	9.02 (9.02)
NO_3^-	3.28 (17.47)	8.41 (14.98)	7.31 (7.32)	16.12 (9.51)	10.28 (12.76)	0.59 (0.59)	17.99 (13.90)	23.06 (33.16)	0.00 (0.00)
Mg^{2+}	0.02 (0.04)	0.05 (0.02)	0.43 (0.04)	0.07 (0.06)	0.20 (0.20)	0.08 (0.15)	0.11 (0.02)	1.27 (0.35)	0.54 (0.08)
Na^+	0.57 (0.04)	1.67 (3.19)	0.42 (0.24)	0.00 (0.00)	1.24 (0.50)	0.74 (0.02)	0.89 (0.23)	1.69 (0.18)	0.46 (0.61)
NH_4^+	3.14 (10.13)	4.06 (8.46)	5.07 (5.44)	16.27 (7.50)	15.24 (9.91)	3.53 (1.15)	10.56 (3.59)	12.69 (14.16)	20.67 (1.55)
SO_4^{2-}	2.36 (4.48)	3.37 (2.51)	12.16 (12.24)	12.38 (14.33)	8.16 (5.54)	2.52 (0.00)	20.42 (4.75)	9.30 (11.55)	24.02 (4.77)

Ba	346.79 (307.94)	8.81 (11.10)	9.60 (8.34)	18.05 (19.02)	18.79 (17.12)	10.76 (3.08)	21.10 (12.69)	27.26 (18.78)	44.72 (3.64)
Ca	652.72 (874.70)	449.33 (577.04)	161.60 (32.94)	324.22 (293.92)	216.65 (97.03)	170.84 (255.81)	721.70 (135.80)	463.89 (307.38)	680.17 (240.43)
Cr	7.05 (8.17)	3.67 (1.82)	4.68 (1.30)	1.28 (3.32)	6.35 (7.09)	3.77 (0.72)	19.73 (23.03)	6.32 (3.52)	2.58 (0.66)
Cu	104.26 (19.65)	21.84 (23.48)	244.86 (4.74)	24.80 (31.25)	22.27 (23.56)	13.94 (1.11)	0.50 (6.55)	42.26 (18.57)	1.55 (1.84)
Fe	634.49 (662.95)	709.08 (499.34)	201.13 (61.86)	526.21 (494.21)	297.38 (130.22)	375.69 (141.31)	638.31 (369.88)	471.29 (430.56)	522.01 (70.16)
K	265.34 (1985.56)	1654.50 (938.94)	1661.06 (244.58)	2606.10 (793.84)	2741.68 (1757.74)	243.08 (290.06)	1294.10 (930.74)	1318.44 (437.28)	1995.04 (55.58)
Mn	58.82 (87.14)	52.86 (30.38)	36.62 (6.28)	47.02 (45.57)	30.76 (25.82)	43.03 (0.64)	92.83 (79.04)	55.58 (48.30)	72.48 (4.63)
Ni	7.59 (1.45)	1.48 (1.66)	33.61 (2.55)	3.91 (5.66)	6.10 (5.52)	0.00 (0.00)	0.39 (8.47)	15.12 (5.83)	0.40 (0.62)
Pb	20.53 (54.65)	31.20 (10.27)	50.82 (12.02)	119.32 (110.52)	98.95 (21.37)	12.17 (3.90)	77.71 (49.95)	50.42 (26.73)	60.03 (17.77)
Se	1.62 (1.80)	2.67 (3.74)	7.43 (0.50)	9.97 (6.42)	3.40 (1.08)	0.10 (0.00)	7.09 (3.11)	10.19 (3.70)	7.37 (4.60)
Ti	234.28 (244.18)	27.24 (31.35)	14.73 (1.40)	33.79 (24.38)	26.62 (10.12)	12.81 (12.00)	35.35 (10.31)	24.95 (31.52)	42.89 (10.53)
Tl	3.56 (1.58)	0.01 (0.02)	1.29 (0.39)	1.55 (2.33)	4.75 (3.55)	0.12 (0.09)	2.77 (1.22)	0.42 (0.16)	0.48 (1.27)

V	17.26 (19.33)	0.85 (1.07)	1.21 (0.23)	0.71 (0.79)	0.25 (0.35)	0.15 (0.00)	0.39 (0.55)	0.07 (0.17)	0.04 (0.06)
Zn	82.66 (175.96)	110.06 (127.17)	282.88 (80.36)	515.62 (355.35)	322.07 (216.71)	87.98 (0.00)	234.07 (160.77)	169.45 (119.04)	145.41 (99.11)

Note. $PM_{2.5}$, Particulate Matter 2.5; OC, organic carbon; EC, elemental carbon; Ca^{2+}, calcium ion; Cl^{-}, chlorine ion; Mg^{2+}, magnesium ion; Na^{+}, sodium ion; K^{+}, potassium ion; NH_4^{+}, ammonium ion; SO_4^{2-}, sulfate ion; NO_3^{-}, nitrate ion; Ba, barium; Ca, calcium; Cr, chromium; Cu, copper; Fe, ferrum; Mn, manganese; K, potassium; Ni, nickel; Pb, lead; Se, selenium; Zn, zinc; V, vanadium; Ti, titanium; Tl, thallium.

Supplementary Table S4. Percent change (95% *CI*) in lung function associated with an IQR increase in $PM_{2.5}$ after adjusted variables in the sensitivity analysis model

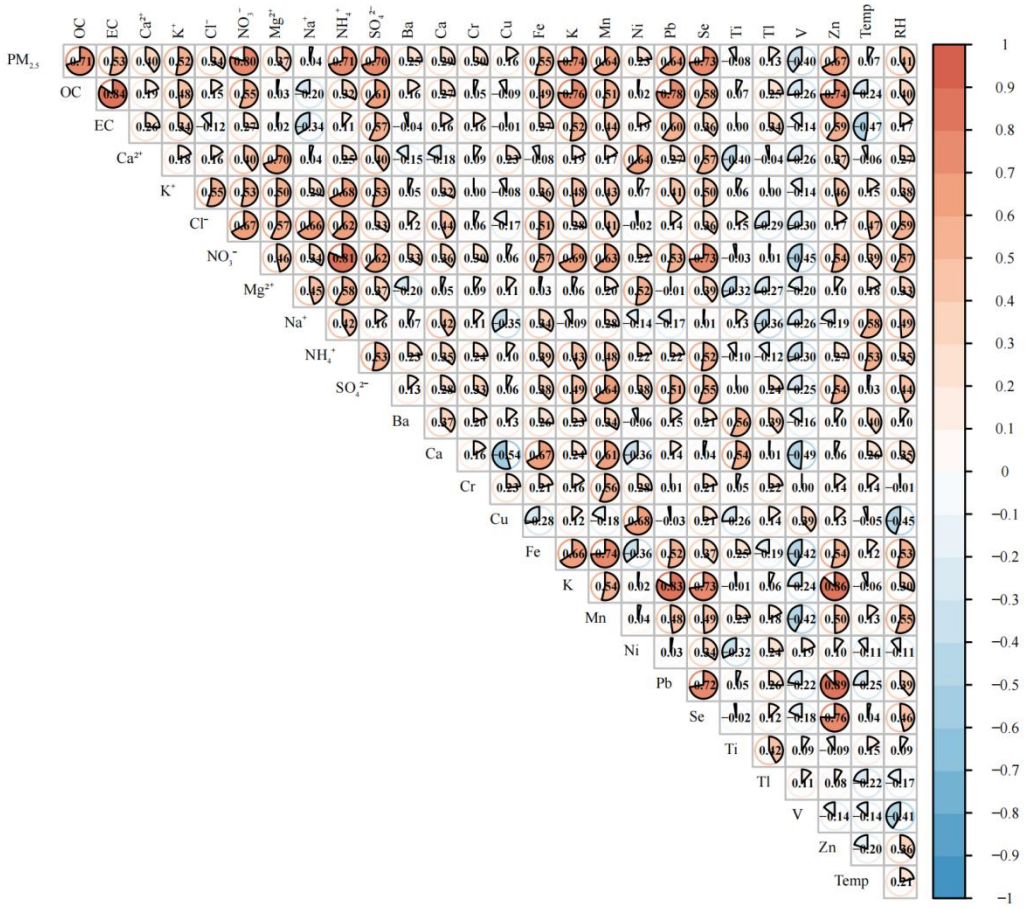
	Percent change (95% *CI*) in lung function associated with an IQR increase in $PM_{2.5}$					
	FVC	FEV_1	FEV_1/FVC	PEF	$FEF_{25\%}$	$FEF_{75\%}$
Model-1	-3.75 (-6.77, -0.64)	-6.56 (-10.05, -2.94)	-2.89 (-5.45, -0.26)	-10.48 (-14.70, -6.05)	-8.71 (-14.14, -2.95)	-3.32 (-8.81, 2.51)
Model-2	-3.72 (-6.73, -0.62)	-6.55 (-10.03, -2.93)	-2.90 (-5.46, -0.27)	-10.44 (-14.66, -6.02)	-9.06 (-14.47, -3.32)	-3.02 (-8.50, 2.79)
Model-3	-3.75 (-6.77, -0.63)	-6.55 (-10.04, -2.92)	-2.88 (-5.44, -0.25)	-10.47 (-14.69, -6.04)	-8.70 (-14.13, -2.93）	-3.30 (-8.79, 2.54)
Model-4	-3.72 (-6.74, -0.61)	-6.53 (-10.02, -2.90)	-2.89 (-5.45, -0.27)	-10.51 (-14.73, -6.07)	-9.08 (-14.46, -3.36)	-3.12 (-8.63, 2.71)
Model-5	-3.93 (-6.94, -0.83)	-6.80 (-10.28, -3.19)	-2.94 (-5.50, -0.31)	-10.70 (-14.92, -6.28)	-8.97 (-14.38, -3.22)	-3.51 (-8.99, 2.31)
Model-6	-3.77 (-6.78, -0.66)	-6.59 (-10.07, -2.97)	-2.90 (-5.46, -0.28)	-10.54 (-14.75, -6.12)	-8.77 (-14.19, -3.01)	-3.22 (-8.82, 2.50)

Note. Model-1 (the main model) was adjusted for gender, age, season, education, BMI (Body Mass Index), current smoking, drinking, temperature and relative humidity as the fixed-effect terms and monitoring site as a random-effect term. Model-2 was model-1 additionally adjusted for income. Model-3 was model-1 additionally adjusted for disease history. Model-4 was model-1 additionally adjusted for physical activity. Model-5 was model-1 additionally adjusted for occupation. Model-6 was model-1 additionally adjusted for medication use. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, one-second rate; PEF, peak expiratory flow; $FEF_{25\%}$, forced expiratory flow at 25% of FVC; $FEF_{75\%}$, forced expiratory flow at 75% of FVC.

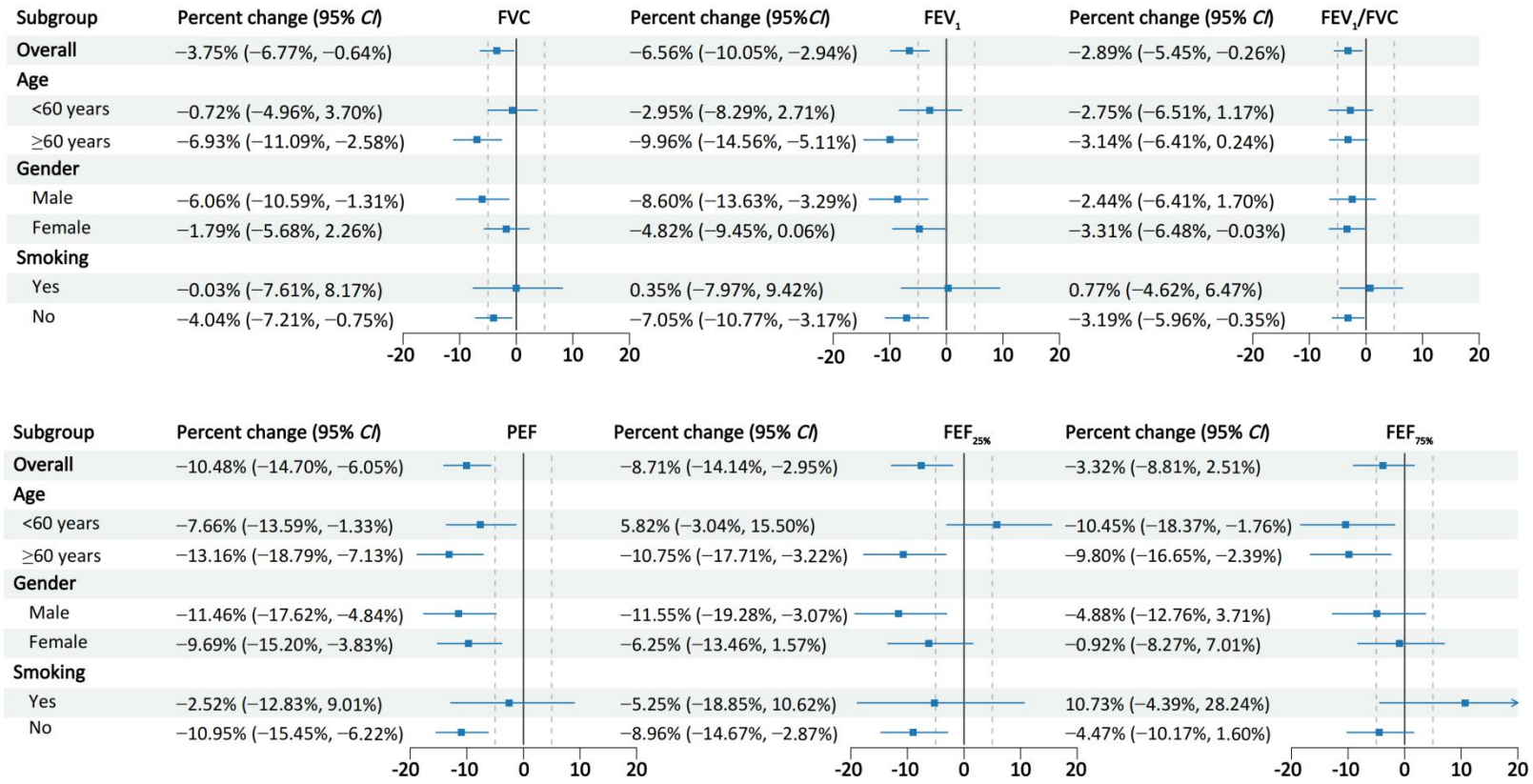
Supplementary Table S5. Percent changes (95% *CI*) in lung function associated with an IQR increase in ambient $PM_{2.5}$ after adjusting for gaseous pollutants

	Percent changes (95% *CI*) in lung function associated with an IQR increase in ambient $PM_{2.5}$					
	FVC	FEV_1	FEV_1/FVC	PEF	$FEF_{25\%}$	$FEF_{75\%}$
Model-1	-3.75 (-6.77, -0.64)	-6.56 (-10.05, -2.94)	-2.89 (-5.45, -0.26)	-10.48 (-14.70, -6.05)	-8.71 (-14.14, -2.95)	-3.32 (-8.81, 2.51)
Model-2	2.89 (-1.71, 7.71)	-1.50 (-6.76, 4.05)	-4.02 (-7.65, -0.25)	-7.41 (-13.65, -0.72)	-5.85 (-13.83, 2.86)	-1.99 (-9.94, 6.67)
Model-3	-1.99 (-5.22, 1.36)	-4.56 (-8.31, -0.65)	-2.72 (-5.43, 0.07)	-9.22 (-13.74, -4.46)	-7.21 (-13.03, -1.00)	-1.28 (-7.19, 5.02)

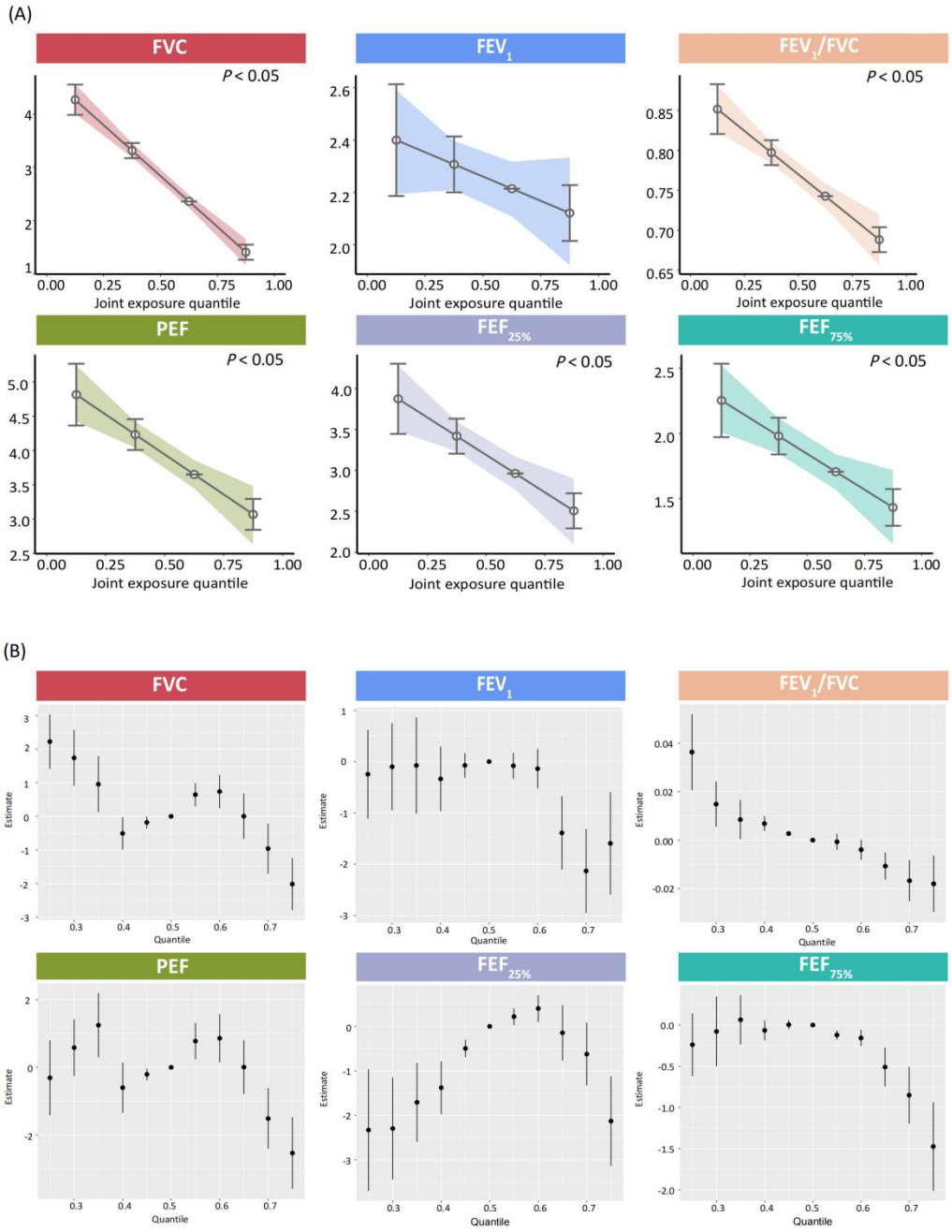
Note. Model-1 (the main model) was adjusted for gender, age, season, education, BMI (Body Mass Index), current smoking, drinking, temperature and relative humidity as the fixed-effect terms and monitoring site as a random-effect term. Model-2 was model-1 additionally adjusted for NO_2. Model-3 was model-1 additionally adjusted for O_3. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, one-second rate; PEF, peak expiratory flow; $FEF_{25\%}$, forced expiratory flow at 25% of FVC; $FEF_{75\%}$, forced expiratory flow at 75% of FVC.



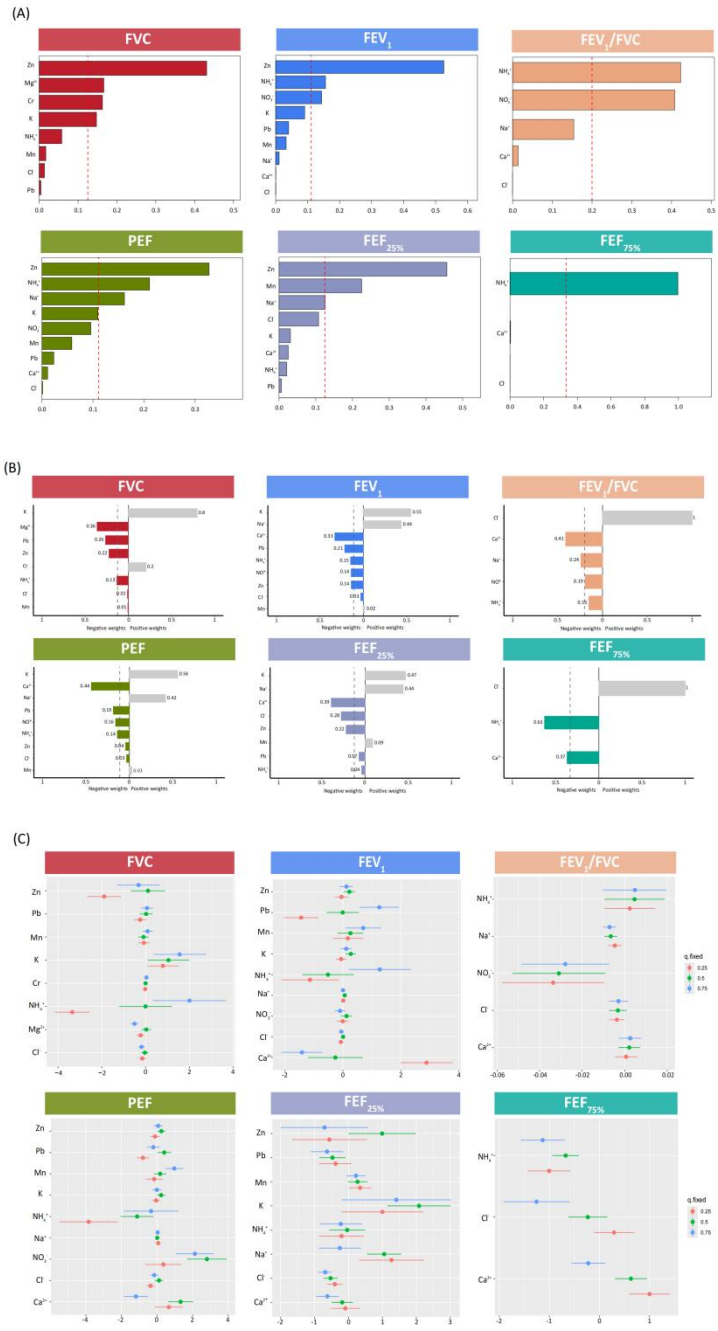
Supplementary Figure S1. The Spearman's correlation coefficients between $PM_{2.5}$ and its components. $PM_{2.5}$, Particulate Matter 2.5; OC, organic carbon; EC, elemental carbon; Ca^{2+}, calcium ion; Cl^{-}, chlorine ion; Mg^{2+}, magnesium ion; Na^{+}, sodium ion; K^{+}, potassium ion; NH_4^{+}, ammonium ion; SO_4^{2-}, sulfate ion; NO_3^{-}, nitrate ion; Ba, barium; Ca, calcium; Cr, chromium; Cu, copper; Fe, ferrum; Mn, manganese; K, potassium; Ni, nickel; Pb, lead; Se, selenium; Zn, zinc; V, vanadium; Ti, titanium; Tl, thallium; TEMP, temperature; RH, relative humidity.



Supplementary Figure S2. Subgroup analysis of the association of $PM_{2.5}$ with lung function. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, one-second rate; PEF, peak expiratory flow; $FEF_{25\%}$, forced expiratory flow at 25% of FVC; $FEF_{75\%}$, forced expiratory flow at 75% of FVC.



Supplementary Figure S3. Joint effect of $PM_{2.5}$ components mixtures on lung function estimated using Qgcomp and BKMR models. (A) The Qgcomp model. (B) The BKMR model. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, one-second rate; PEF, peak expiratory flow; $FEF_{25\%}$, forced expiratory flow at 25% of FVC; $FEF_{75\%}$, forced expiratory flow at 75% of FVC.



Supplementary Figure S4. Weight proportion of each $PM_{2.5}$ component in the joint effects on lung function estimated using WQS, Qgcomp, and BKMR models. (A) The WQS model. (B) The Qgcomp model. (C) The BKMR model. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, one-second rate; PEF, peak expiratory flow; $FEF_{25\%}$, forced expiratory flow at 25% of FVC; $FEF_{75\%}$, forced expiratory flow at 75% of FVC; Ca^{2+}, calcium ion; Cl^-, chlorine ion; Mg^{2+}, magnesium ion; Na^+, sodium ion; NH_4^+, ammonium ion; NO_3^-, nitrate ion; Cr, chromium; K, potassium; Mn, manganese; Pb, lead; Zn, zinc.