Supplementary Material

Air Pollution Associated Respiratory Mortality Risk Alleviated by Residential Greenness in the Chinese Elderly Health Service Cohort

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Long-term $PM_{2.5}$ exposure assessment

We used a satellite-based spatiotemporal model to estimate the annual concentration of $PM_{2.5}$ at the residential address of each participant between 1998 and 2011, as previously described (Sun et al. 2016; Wong et al. 2015; Zhang et al. 2017). Briefly, we predicted baseline $PM_{2.5}$ exposure based on Surface Extinction Coefficients (SEC) from Aerosol Optical Depth (AOD) retrieved from remote sensing data of the two National Aeronautics and Space Administration (NASA) Earth Observing System satellites (NASA (National Aeronautics and Space Administration) 2013). AOD data were originally retrieved at a 10km ×10km resolution, and were refined into 1km ×1km resolution by modifying the Moderate Resolution Imaging Spectroradiometer (MODIS) algorithm (Li et al. 2005). The relationship between SEC and $PM_{2.5}$ for each year from 1998 to 2001 was calibrated using grid cells with both SEC and $PM_{2.5}$ measurements. This yearly calibration was then used to predict $PM_{2.5}$ at the residential location of each participant.

Nested case-control study

We conducted the nested case-control study as a sensitivity analysis to assess the association between air pollution and respiratory mortality. Compared to cohort study with studying time-varying exposures, such as ambient temperature and air pollution, the nested case-control study is computational efficient and estimates are similar to the ones obtained from the entire cohort (Beverland et al. 2012; Essebag et al. 2005; Goldstein and Langholz 1992; Sun et al. 2016). Details of the nested case-control study have been described elsewhere (Beverland et al. 2012; Essebag et al. 2005; Goldstein and Langholz 1992; Sun et al. 2016).

We adopted the same way to constructed nested case-control risk sets as we did to assess the mortality effects of ambient temperature (Sun et al. 2016). Briefly, controls were selected by matching follow-up time, calendar year and month, and date of birth (±1 calendar year) with the case. We excluded controls when associated date was outside the follow-up period of the cohort. We randomly selected 9 controls to each case from all eligible subjects in the cohort (Beverland et al. 2012).

We fitted a conditional logistic regression after controlled for individual-level confounders including sex, age, smoking status (never, quit, and current smoker), alcohol drinking (never/social, and former/regular drinker), body mass index (BMI) (<21.6, 21.6-26.3, and >26.3 kg/m^2), medication taken (yes or no), monthly expenses (<128, 128-384, and ≥ 385 USD), education attainment (≥ secondary, primary, and < primary), physical activity, and baseline annual concentration of $PM_{2.5}$ to represent long-term air pollution exposure, tertiary planning unit (TPU)-level confounders including proportion of old people (age ≥ 65 years), proportion of tertiary education, and monthly domestic household income, and district-level proportion of smoker. We also controlled for time-varying confounders including influenza epidemics, day of the week, ambient temperature (natural cubic spline with three degrees of freedom), and relative humidity (natural cubic spline with three degrees of freedom). The formula is as follows:

$$\text{Logit}(p) = \alpha + \text{COVs} + \beta\text{Greenness} + \gamma\text{AP} + \lambda\text{Greenness}\times\text{AP}$$

Where COVs represents all other covariates in the model including age, sex, smoking status, alcohol drinking, BMI, medication taken, monthly expenses, education attainment, physical activity, and baseline yearly concentration of $PM_{2.5}$, TPU-level confounders including proportion of old people (age ≥ 65 years), proportion of tertiary education, and monthly domestic household income, district-level proportion of smoker, influenza epidemics, day of the week, and relative humidity (natural cubic spline with three degrees of freedom). Greenness is greenness quartiles, and Quartile 1 is the reference group. AP is air pollution ($PM_{2.5}$, PM_{10}, NO_2, and O_3). λ is the vector of coefficients representing the additional excess risks in greenness Quartile 2 to 4 compared to risk in greenness Quartile 1.

Table S1. Literature review on the modification effects of greenness on the adverse health effects of air pollution.

Publication	Country	Air pollutants	Health outcomes	Greenness definition	Main relevant findings
Vivanco-Hidalgo RM et al., 2018 (Vivanco-Hidalgo et al. 2018)	Barcelona, Spain	$PM_{2.5}$ and BC	Ischemic stroke and its subtypes	NDVI at 100, 300, and 500m buffer	No evidence to indicate the association between $PM_{2.5}$ and BC and the risk of large artery strokes varied by levels of residential greenness.
Heo S and Bell ML, 2019 (Heo and Bell 2019)	364 USA counties	$PM_{2.5}$ and PM_{10}	Cause-specific hospitalizations	NDVI at 250m buffer	The association between air pollution and health was less in areas with more green space.
Keijzer CD et al., 2016 (de Keijzer et al. 2017)	2148 small areas in Spain	PM_{10}, $PM_{2.5}$, NO_2, and O_3	All-natural mortality	NDVI calculated for all small areas	A protective effect of greenness on mortality effects of air pollution was only found in areas with lower socioeconomic status.
Dimitrova DD and Dzhambov AM et al., 2017 (Dimitrova and Dzhambov 2017)	34 European countries	Questionnaire asking whether you have problems with air quality	A validated 5-category question about self-rated health with the response options "very good", "good", "fair", "bad", and "very bad"	Questionnaire asking the question "how would you describe your access to: Recreational or green areas?", with the response options: "With great difficulty", "with some difficulty", "easily", "very easily" and "service not used"	The risk of air quality on poor self-rated health was higher among participants not using green areas in their neighborhood or reporting a difficult access to those areas.
Yitshak-Sade M, et al. 2019 (Yitshak-Sade et al. 2019)	Massachusetts, USA	$PM_{2.5}$	Cardiovascular mortality	NDVI at 250m and 1250m buffer	The risk of cardiovascular mortality associated with exposure to $PM_{2.5}$ was not modified by neighborhood greenness.
Kloumourtzoglou MA et al., 2016 (Kioumourtzoglou et al. 2016)	207 US cities	$PM_{2.5}$	CHF, MI, COPD, and diabetes	NDVI at 250m buffer	Higher $PM_{2.5}$ effect estimates associated with increasing levels of greenness.

Abbreviations: $PM_{2.5}$ = particulate matter with an aerodynamic diameter ≤ 2.5 μm; PM_{10} = particulate matter with an aerodynamic diameter ≤ 10 μm; NO_2 = nitrogen dioxide; O_3 = ozone; CHF=congestive heart failure; MI=myocardial infarction; COPD=chronic obstructive pulmonary disease.

Table S2. Percent excess risk and 95% confidence interval of respiratory mortality per 10μg/m^3 increase in air pollutants at 4-day moving average in the low and high residential greenness areas measured by normalized difference vegetation index with 500m[a].

Mortality	Air pollutant	Low greenness	High greenness	*p*-Value
Total respiratory	$PM_{2.5}$	1.25 (-3.14, 5.66)	-1.11 (-5.53, 3.32)	0.440
	PM_{10}	1.06 (-2.07, 4.20)	-0.88 (-4.00, 2.24)	0.370
	NO_2	3.96 (-0.69, 8.63)	-1.80 (-6.50, 2.93)	0.069
	O_3	2.16 (-2.23, 6.57)	-2.23 (-6.72, 2.28)	0.147
Pneumonia	$PM_{2.5}$	3.05 (-2.46, 8.59)	-3.36 (-8.85, 2.16)	0.094
	PM_{10}	1.87 (-1.97, 5.71)	-2.01 (-5.77, 1.77)	0.143
	NO_2	5.19 (-0.61, 11.01)	-3.88 (-9.82, 2.10)	**0.022**
	O_3	2.47 (-2.94, 7.90)	-4.61 (-10.10, 0.92)	0.057
COPD	$PM_{2.5}$	-0.42 (-8.34, 7.56)	6.55 (-1.62, 14.79)	0.215
	PM_{10}	0.50 (-5.25, 6.29)	4.73 (-1.57, 11.08)	0.312
	NO_2	2.23 (-6.28, 10.81)	7.05 (-1.19, 15.36)	0.399
	O_3	0.54 (-7.52, 8.67)	6.18 (-2.24, 14.67)	0.315

Abbreviations: $PM_{2.5}$=particulate matter ≤2.5μm in aerodynamic diameter; PM_{10}=particulate matter ≤10μm in aerodynamic diameter; NO_2=nitrogen dioxide; O_3=ozone; COPD=chronic obstructive pulmonary disease.

[a]Low and high greenness were defined by the median (0.105) of normalized difference vegetation index within 500m.

Table S3. Additional percent excess risk in respiratory mortality associated with 10μg/m^3 increase in air pollutants at the 4-day moving average by greenness quartiles within 500m.

Mortality	Air pollutant	Quartile 1 (lowest)	Quartile 2	Quartile 3	Quartile 4 (highest)	*p* for trend
Total respiratory	$PM_{2.5}$	Reference	-5.01 (-13.40, 3.44)	-6.30 (-14.70, 2.14)	-3.45 (-12.00, 5.16)	0.425
	PM_{10}	Reference	0.57 (-5.45, 6.62)	-1.74 (-7.59, 4.15)	-1.56 (-7.73, 4.66)	0.500
	NO_2	Reference	-3.31 (-11.90, 5.39)	-11.80 (-20.50, -3.08)	-2.91 (-11.60, 5.89	0.302
	O_3	Reference	-5.61 (-13.80, 2.68)	-7.66 (-16.00, 0.72)	-6.76 (-15.10, 1.60)	0.106
Pneumonia	$PM_{2.5}$	Reference	-4.49 (-15.00, 6.10)	-7.51 (-17.90, 3.00)	-9.96 (-20.60, 0.80)	0.059
	PM_{10}	Reference	1.65 (-5.72, 9.07)	-0.95 (-7.98, 6.13)	-5.83 (-13.50, 1.88)	0.104
	NO_2	Reference	-2.65 (-13.30, 8.14)	-11.20 (-21.90, -0.47)	-9.34 (-20.20, 1.65)	**0.047**
	O_3	Reference	-7.96 (-18.10, 2.28)	-9.47 (-19.70, 0.85)	-12.60 (-22.80, -2.37)	**0.018**
COPD	$PM_{2.5}$	Reference	-5.30 (-20.50, 10.10)	-2.16 (-17.60, 13.60)	11.00 (-4.91, 27.10)	0.151
	PM_{10}	Reference	-1.47 (-12.50, 9.69)	-1.59 (-12.90, 9.87)	9.60 (-2.34, 21.70)	0.157
	NO_2	Reference	-0.44 (-16.50, 15.90)	-7.01 (-23.10, 9.36)	16.10 (-0.15, 32.60)	0.074
	O_3	Reference	-2.61 (-17.70, 12.70)	-0.55 (-16.20, 15.30)	9.00 (-6.66, 24.90)	0.237

Abbreviations: $PM_{2.5}$=particulate matter ≤2.5μm in aerodynamic diameter; PM_{10}=particulate matter ≤10μm in aerodynamic diameter; NO_2=nitrogen dioxide; O_3=ozone; COPD=chronic obstructive pulmonary disease.

Table S4. Additional percent excess risk in respiratory mortality associated with $10 \mu g/m^3$ increase in air pollutants at the 4-day moving average by greenness quartiles within 250m in the nested case-control study[a].

Mortality	Air pollutant	Quartile 1 (lowest)	Quartile 2	Quartile 3	Quartile 4 (highest)	*p* for trend
Total respiratory	$PM_{2.5}$	Reference	3.21 (-3.43, 9.85)	-3.21 (-9.82, 3.40)	-2.33 (-8.76, 4.11)	0.209
	PM_{10}	Reference	2.53 (-2.00, 7.05)	-1.12 (-5.64, 3.41)	-1.69 (-6.21, 2.83)	0.190
	NO_2	Reference	1.30 (-3.28, 5.88)	-5.65 (-10.30, -0.97)	-2.47 (-7.12, 2.18)	**0.038**
	O_3	Reference	-5.10 (-11.30, 1.09)	-4.24 (-10.50, 1.99)	-6.99 (-13.10, -0.89)	0.051
Pneumonia	$PM_{2.5}$	Reference	5.54 (-2.58, 13.60)	-3.49 (-11.70, 4.70)	-4.99 (-13.00, 3.05)	0.057
	PM_{10}	Reference	4.03 (-1.43, 9.50)	-0.60 (-6.16, 4.95)	-3.25 (-8.93, 2.44)	0.077
	NO_2	Reference	1.80 (-3.60, 7.20)	-6.29 (-11.90, -0.65)	-6.36 (-12.00, -0.68)	**0.002**
	O_3	Reference	-5.10 (-12.50, 2.32)	-6.22 (-13.70, 1.30)	-9.71 (-17.10, -2.32)	**0.013**
COPD	$PM_{2.5}$	Reference	4.68 (-8.70, 18.10)	-3.02 (-16.10, 10.10)	4.60 (-7.87, 17.10)	0.658
	PM_{10}	Reference	4.29 (-4.92, 13.50)	-2.05 (-11.20, 7.05)	2.50 (-6.08, 11.10)	0.851
	NO_2	Reference	5.57 (-4.26, 15.40)	-4.13 (-13.90, 5.65)	9.65 (0.29, 19.00)	0.166
	O_3	Reference	--3.64 (-16.60, 9.31)	0.60 (-12.50, 13.70)	0.44 (-12.20, 13.10)	0.706

Abbreviations: $PM_{2.5}$=particulate matter ≤2.5μm in aerodynamic diameter; PM_{10}=particulate matter ≤10μm in aerodynamic diameter; NO_2=nitrogen dioxide; O_3=ozone; COPD=chronic obstructive pulmonary disease.

[a]Greenness quartiles were based on quartiles of NDVI of cases. The additional percent changes were adjusted for age, sex, smoking status, alcohol consumption, physical activity, BMI, education attainment, medication taken, personal monthly expenses, TPU-level confounders including proportion of old people (age ≥ 65 years), proportion of tertiary education, and monthly domestic household income, district-level proportion of smoker, day of the week, ambient temperature, relative humidity, baseline concentration of $PM_{2.5}$, and influenza epidemics.

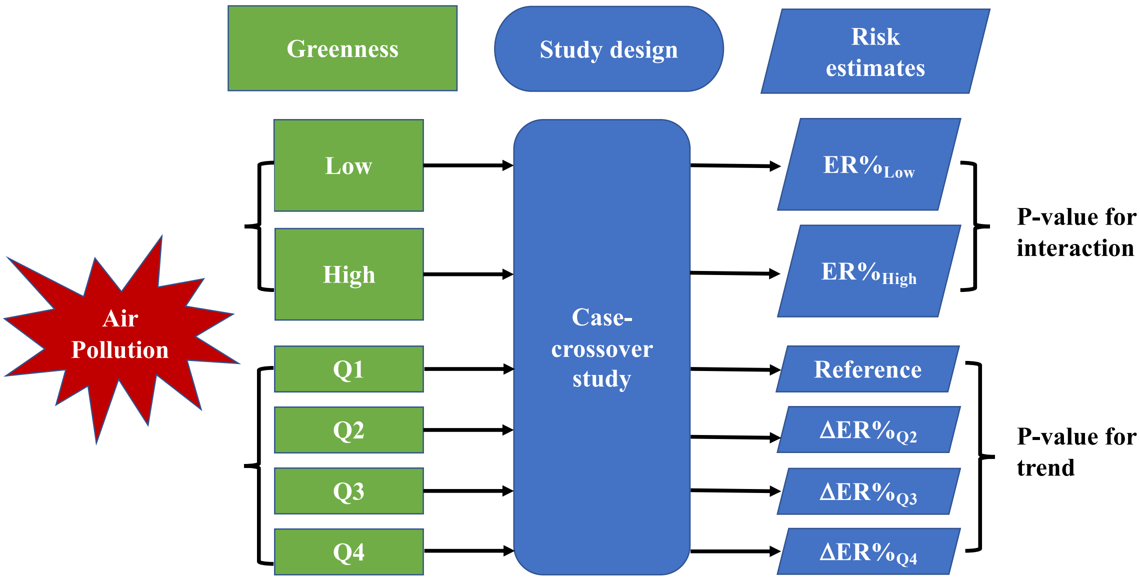

Fig. S1. Flowchart of data analysis.

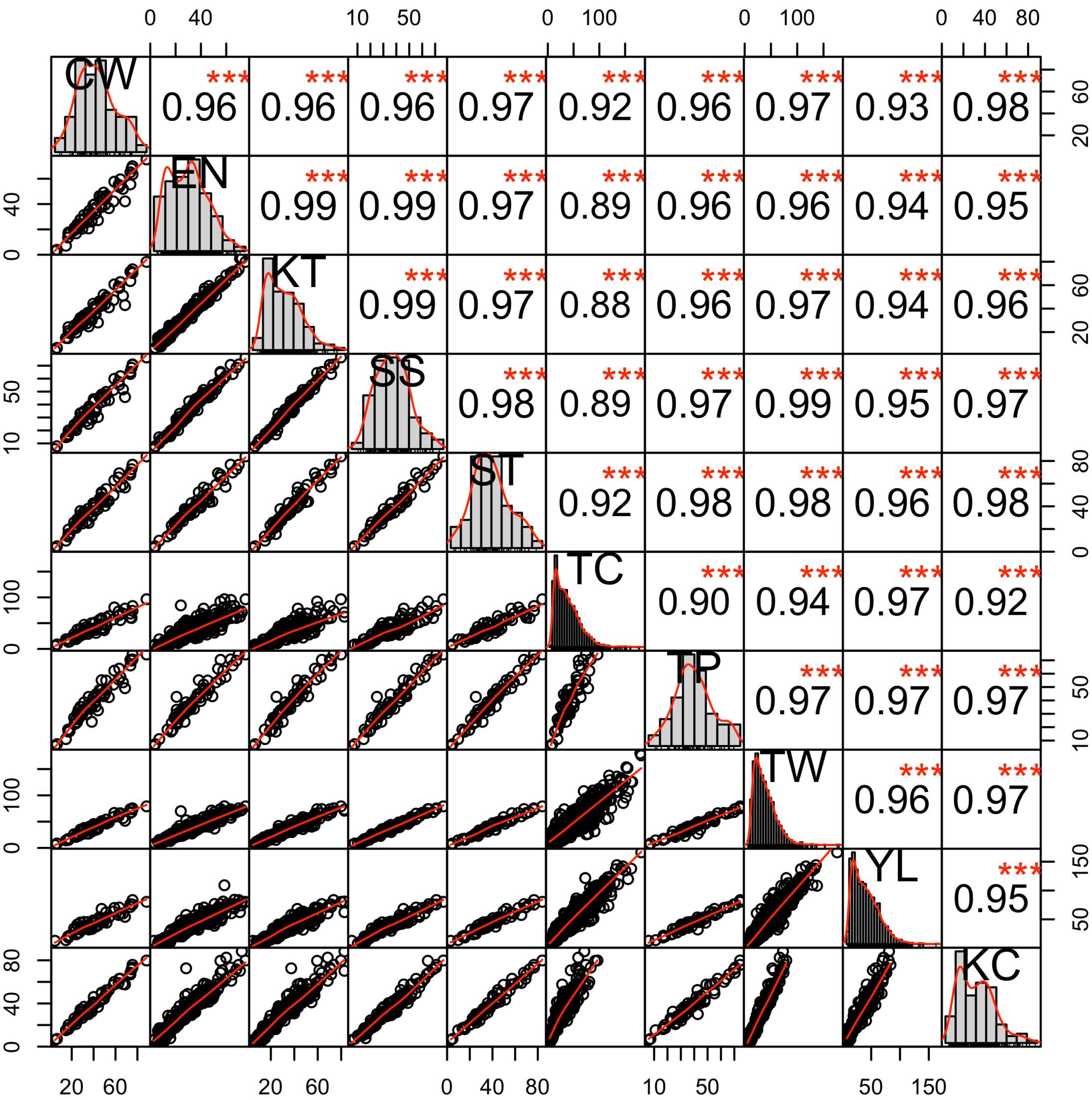

Fig. S2. Correlation matrix for fine particulate matter ($PM_{2.5}$) among ten air monitoring stations in Hong Kong.

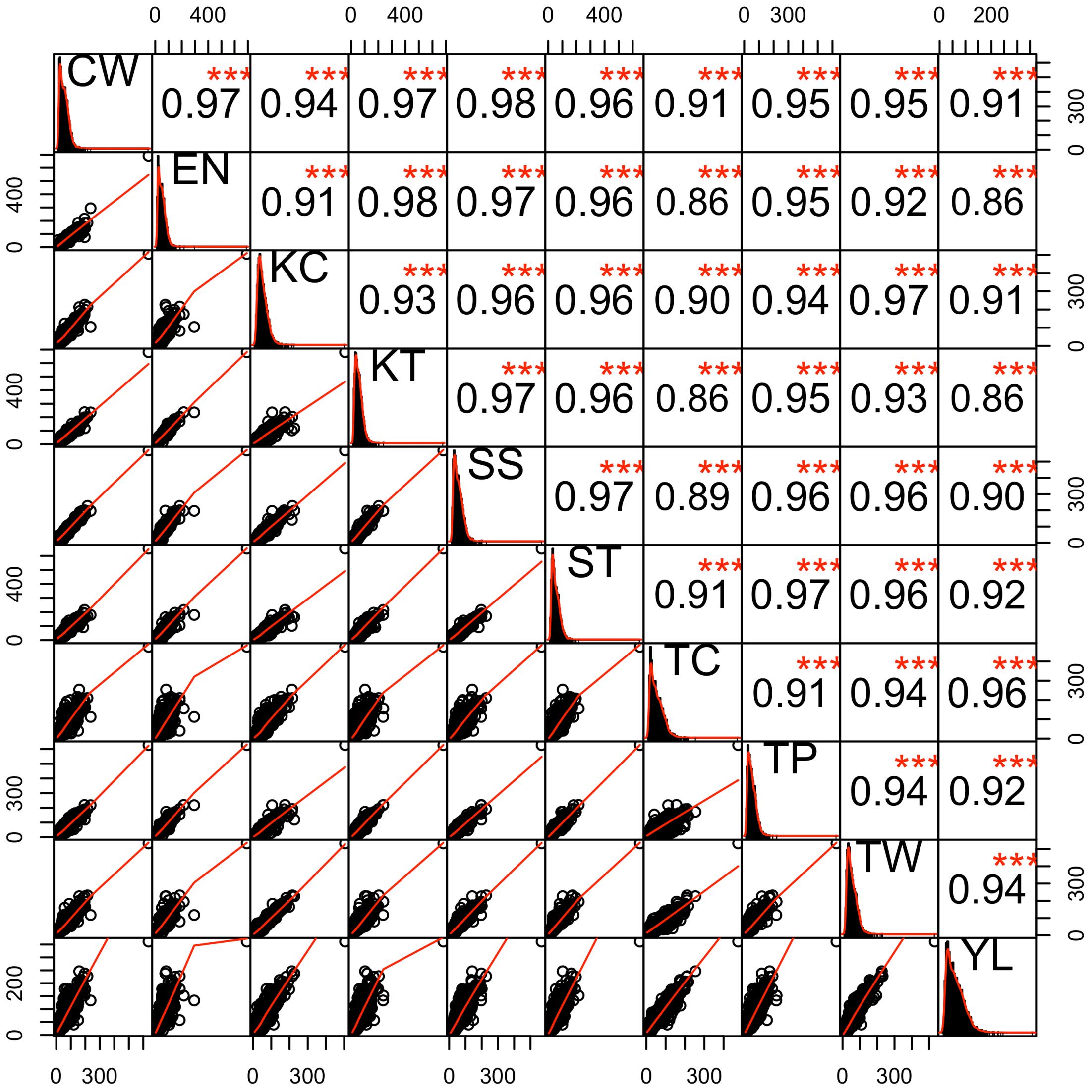

Fig. S3. Correlation matrix for respirable particulate matter (PM_{10}) among ten air monitoring stations in Hong Kong.

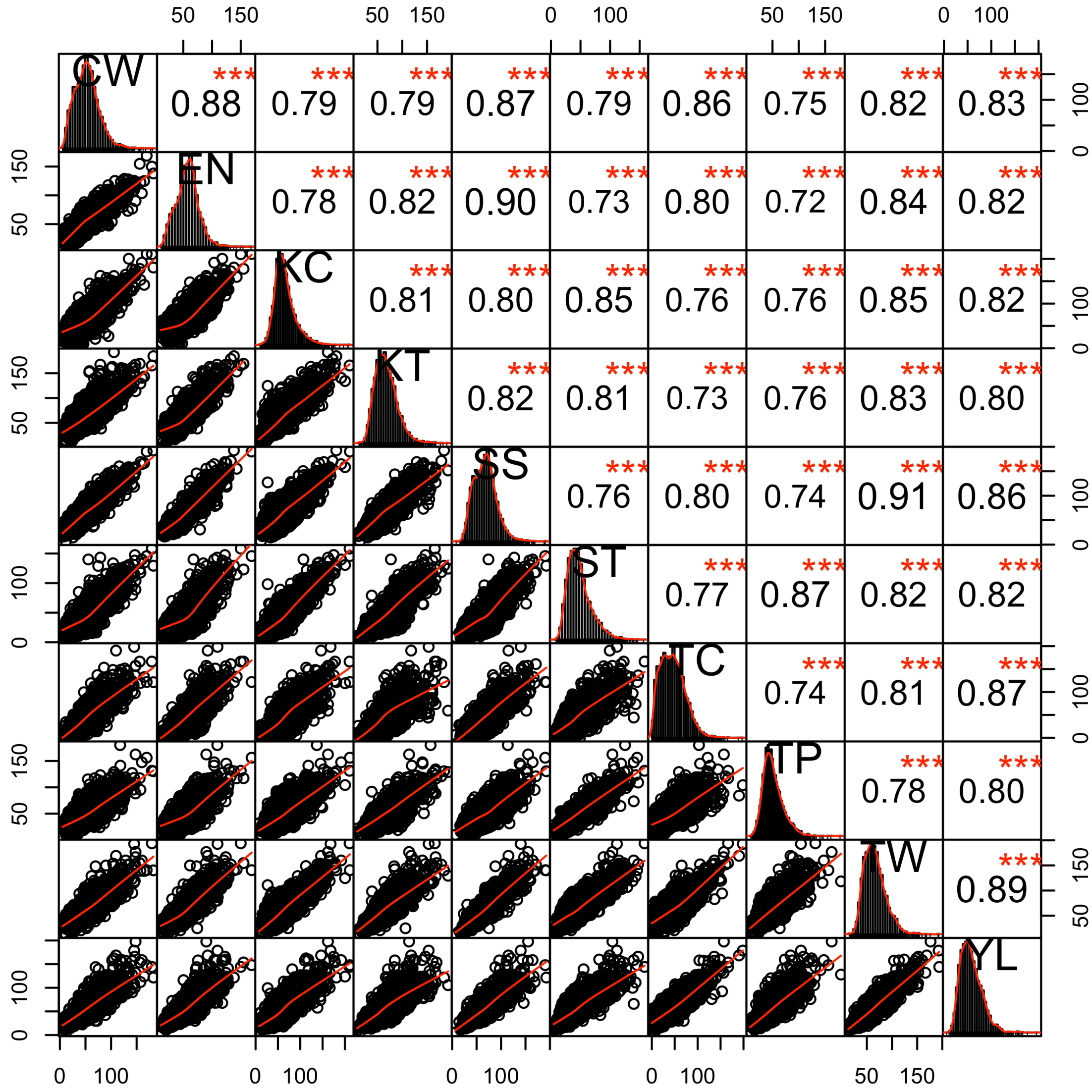

Fig. S4. Correlation matrix for nitrogen dioxide (NO_2) among ten air monitoring stations in Hong Kong.

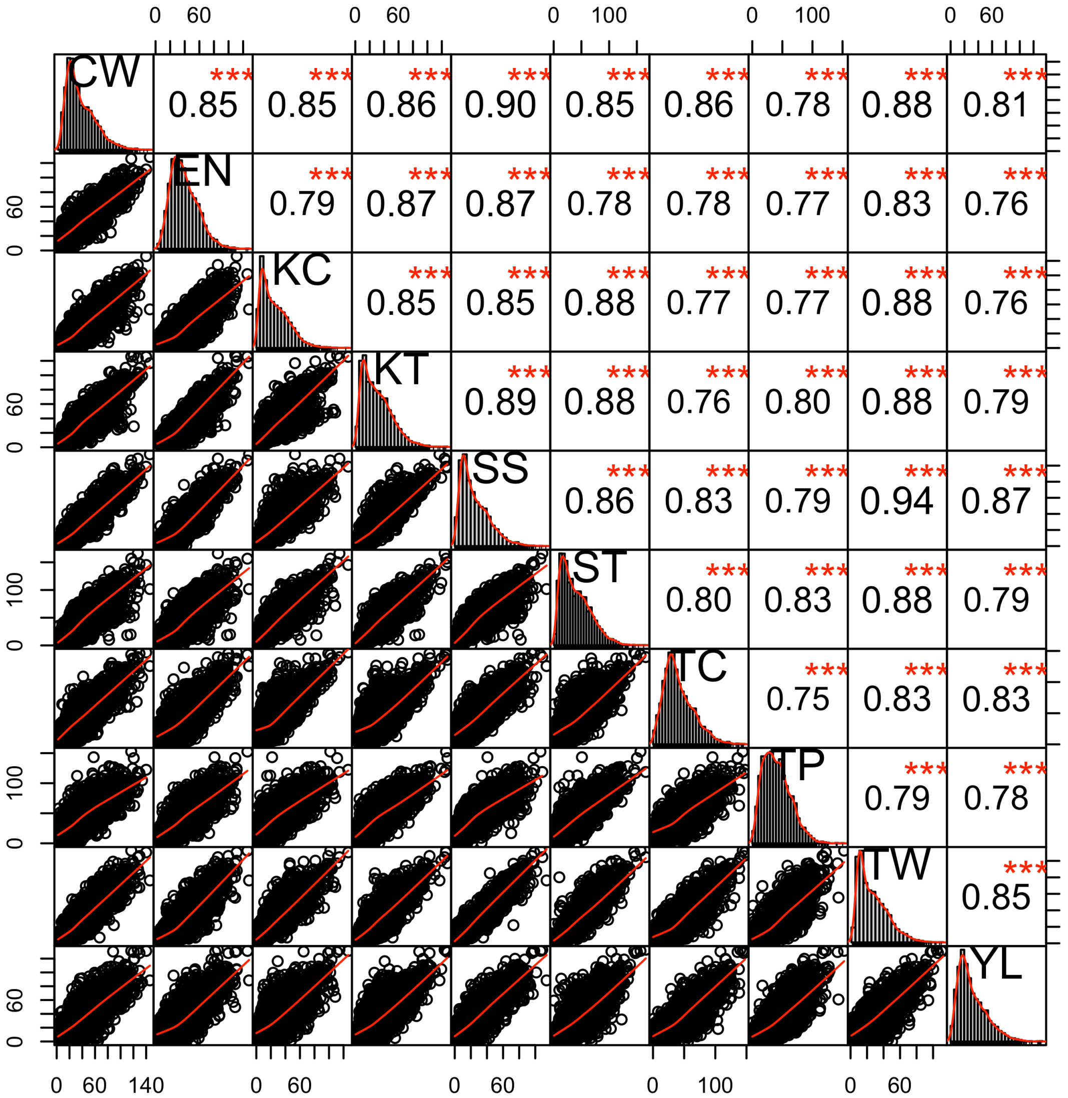

Fig. S5. Correlation matrix for ozone (O_3) among ten air monitoring stations in Hong Kong.

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