

The impact of air pollution on cardiovascular and respiratory mortality in Makkah, Saudi Arabia, during the Hajj cultural events and COVID-19 outbreak

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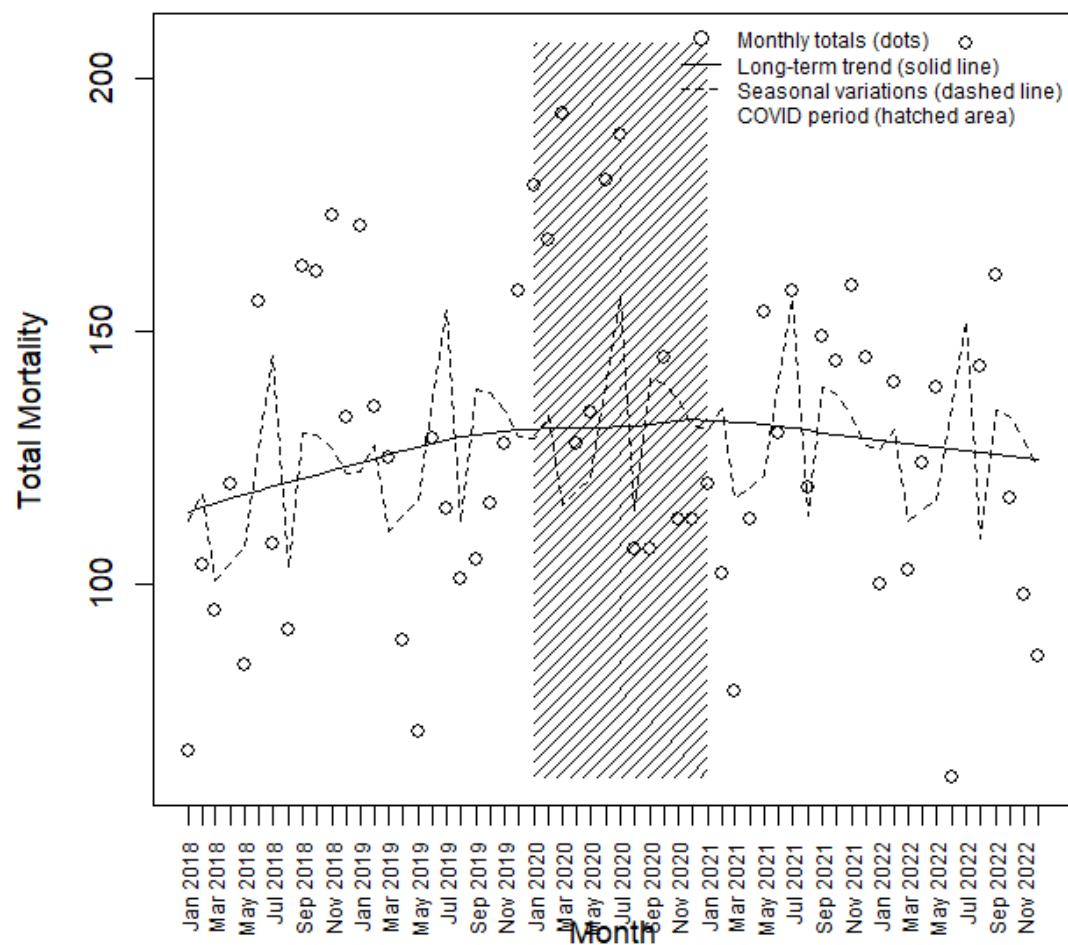
Table of Contents

1. Time Series Plots for Cardiovascular and Respiratory Mortality	3
○ Time series trends for Cardiovascular mortality	3
○ Time series trends for Respiratory mortality.....	4
2. Cardiovascular Mortality Models	5
○ Interaction Effect Models for Cardiovascular Mortality.....	5
○ Table 1: PM10 during COVID Year	5
○ Table 2: PM10 during Hajj Events	5
○ Table 3: PM10 during Any Event	6
○ Table 4: NO ₂ during COVID Year	6
○ Table 5: NO ₂ during Hajj Events.....	7
○ Table 6: NO ₂ during Any Event.....	7
○ Table 7: SO ₂ during COVID Year.....	8
○ Table 8: SO ₂ during Hajj Events.....	8
○ Table 9: SO ₂ during Any Event	9
○ Table 10: O ₃ during COVID Year	9
○ Table 11: O ₃ during Hajj Events	10
○ Table 12: O ₃ during Any Event	10
○ Total Effect Models for Cardiovascular Mortality.....	11
○ Table 13: PM10 during COVID Year	11
○ Table 14: PM10 during Hajj Events	11
○ Table 15: PM10 during Any Event	12
○ Table 16: NO ₂ during COVID Year.....	12
○ Table 17: NO ₂ during Hajj Events	13
○ Table 18: NO ₂ during Any Event	13
○ Table 19: SO ₂ during COVID Year	14
○ Table 20: SO ₂ during Hajj Events	14
○ Table 21: SO ₂ during Any Event	15
○ Table 22: O ₃ during COVID Year	15

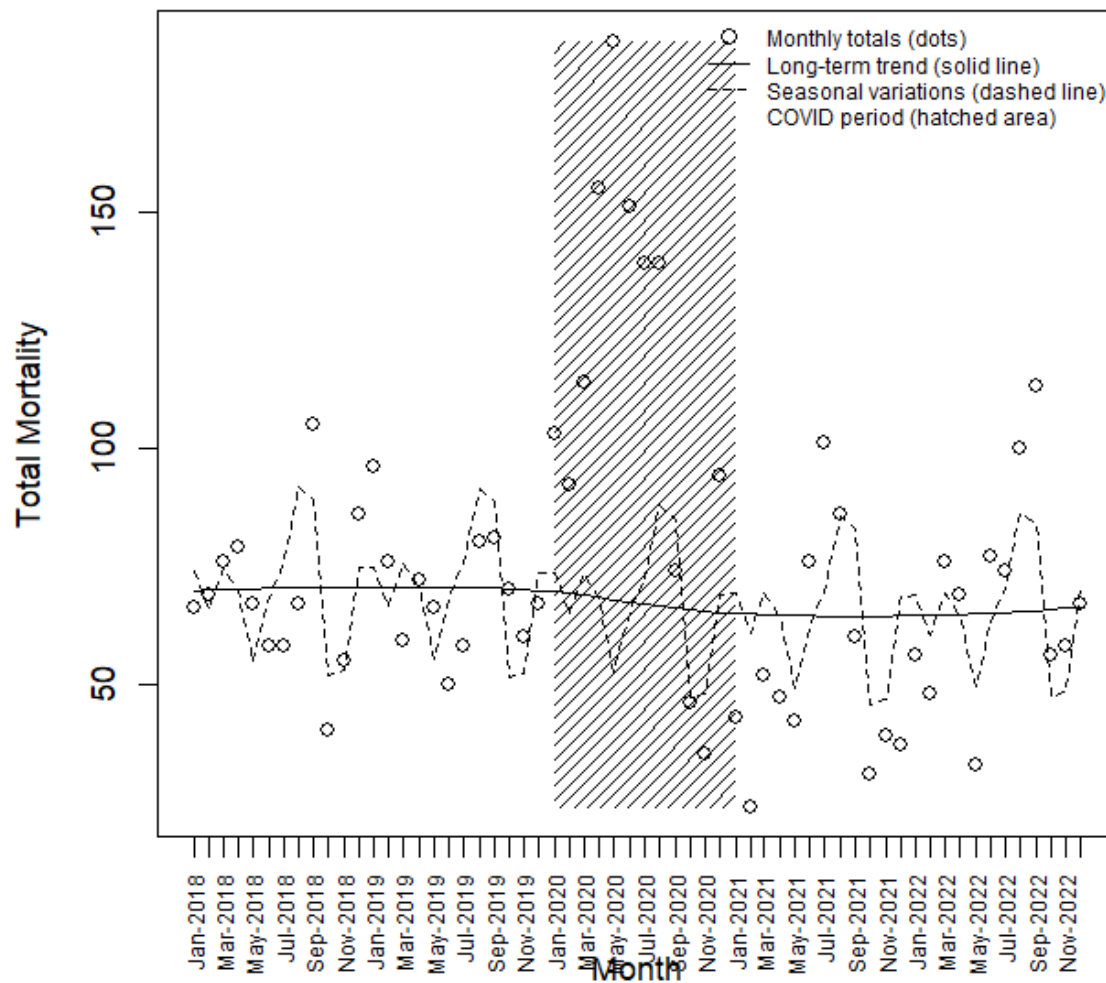
○ Table 23: O ₃ during Hajj Events.....	16
○ Table 24: O ₃ during Any Event.....	16
3. Respiratory Mortality Models	17
○ Interaction Effect Models for Respiratory Mortality.....	17
○ Table 1: PM10 during COVID Year	17
○ Table 2: PM10 during Hajj Events	17
○ Table 3: PM10 during Any Event	18
○ Table 4: NO ₂ during COVID Year.....	18
○ Table 5: NO ₂ during Hajj Events	19
○ Table 6: NO ₂ during Any Event	19
○ Table 7: SO ₂ during COVID Year	20
○ Table 8: SO ₂ during Hajj Events.....	20
○ Table 9: SO ₂ during Any Event.....	21
○ Table 10: O ₃ during COVID Year	21
○ Table 11: O ₃ during Hajj Events.....	22
○ Table 12: O ₃ during Any Event.....	22
○ Total Effect Models for Respiratory Mortality.....	23
○ Table 13: PM10 during COVID Year	23
○ Table 14: PM10 during Hajj Events	23
○ Table 15: PM10 during Any Event	24
○ Table 16: NO ₂ during COVID Year	24
○ Table 17: NO ₂ during Hajj Events	25
○ Table 18: NO ₂ during Any Event	25
○ Table 19: SO ₂ during COVID Year	26
○ Table 20: SO ₂ during Hajj Events	26
○ Table 21: SO ₂ during Any Event	27
○ Table 22: O ₃ during COVID Year	27
○ Table 23: O ₃ during Hajj Events.....	28
○ Table 24: O ₃ during Any Event.....	28
4. Estimated Relative Risk (RR) of Pollutants on Respiratory and Cardiovascular Mortality.....	29
○ Table 25: RR per IQR of PM10, NO ₂ , SO ₂ , and O ₃ on Respiratory Mortality	29
○ Table 26: RR per IQR of PM10, NO ₂ , SO ₂ , and O ₃ on Cardiovascular Mortality	30

1- Time Series Plots for Cardiovascular and Respiratory Mortality:

-Time series trends for Cardiovascular mortality. Dots show monthly totals; the black line represents long-term trends, and the red line shows seasonal variations.



-Time series trends for respiratory mortality. Dots show monthly totals; the black line represents long-term trends, and the red line shows seasonal variations.



2-Cardiovascular mortality models:

-Interaction effect models Cardiovascular mortality:

Table 1: (Effect modification model for PM₁₀ during COVID Year) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Std Error
PM ₁₀	0.007**	0.004
COVID Year	1.618***	0.277
Seasonal	0.007***	0.001
Trend	0.009***	0.003
Hajj Events	0.073	0.047
PM ₁₀ : COVID Year Interaction	-0.036***	0.007
Constant	3.332***	0.499

Table 2: (Effect modification model for PM₁₀ during Hajj Events) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Std Error
PM ₁₀	-0.002	0.003
Hajj Events	0.777*	0.445
Seasonal	0.006***	0.001
Trend	0.005	0.003
COVID Year	0.108***	0.037
PM ₁₀ : Hajj Events	-0.013	0.009
Constant	4.307***	0.465

Table 3:(Effect modification model for PM₁₀ during Any Event) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Std Error
PM ₁₀	0.010***	0.004
Any Event	1.080***	0.206
Seasonal	0.007***	0.001
Trend	0.008***	0.003
PM ₁₀ : Any Event	-0.021***	0.005
Constant	3.270***	0.500

Table 4: (Effect modification model for NO₂ during COVID) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Std Error
NO ₂	0.008**	0.004
COVID Year	0.345*	0.199
Seasonal	0.007***	0.001
Trend	0.005*	0.003
Hajj Events	0.100**	0.041
NO ₂ : COVID Year Interaction	-0.011	0.010
Constant	4.036***	0.346

Table 5:(Effect modification model for NO₂ during Hajj Events) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Std Error
NO ₂	0.004	0.004
Hajj Events	-0.528**	0.265
Seasonal	0.005***	0.001
Trend	0.006**	0.003
COVID Year	0.119***	0.031
NO ₂ : Hajj Events Interaction	0.033**	0.014
Constant	4.023***	0.346

Table 6:(Effect modification model for NO₂ during Any Event) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Std Error
NO ₂	0.005	0.004
Any Event	-0.052	0.173
Seasonal	0.006***	0.001
Trend	0.006**	0.003
NO ₂ : Any Event Interaction	0.009	0.009
Constant	3.998***	0.337

Table 7:(Effect modification model for SO₂ during COVID) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Std Error
SO ₂	-0.003***	0.001
COVID Year	-0.244***	0.079
Seasonal	0.006***	0.001
Trend	-0.003	0.004
Hajj Events	0.128***	0.041
SO ₂ : COVID Year Interaction	0.010***	0.002
Constant	5.405***	0.535

Table 8:(Effect modification model for SO₂ during Hajj Events) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Std Error
SO ₂	0.0003	0.001
Hajj Events	0.416***	0.107
Seasonal	0.005***	0.001
Trend	0.006	0.004
COVID Year	0.116***	0.033
SO ₂ : Hajj Events	-0.006***	0.002
Constant	4.088***	0.494

Table 9:(Effect modification model for SO₂ during Any Event) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
SO ₂	-0.001	(0.001)
Any Event	0.082	(0.068)
Seasonal	0.007***	(0.001)
Trend	0.003	(0.004)
SO ₂ : Any Event	0.001	(0.001)
Constant	4.494***	(0.520)

Table 10:(Effect modification model for O₃ during COVID) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
O ₃	-0.002	(0.003)
COVID Year	0.660***	(0.207)
Seasonal	0.007***	(0.001)
Trend	0.006**	(0.003)
Hajj Events	0.074*	(0.041)
O ₃ : COVID Year	-0.020**	(0.008)
Constant	4.090***	(0.348)

Table 11: (Effect modification model for O₃ during Hajj Events) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
O ₃	-0.006**	(0.003)
Hajj Events	-1.596***	(0.418)
Seasonal	0.007***	(0.001)
Trend	0.007***	(0.003)
COVID Year	0.162***	(0.032)
O ₃ : Hajj Events	0.067***	(0.016)
Constant	4.036***	(0.349)

Table 12:(Effect modification model for O₃ during Any Event) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
O ₃	-0.005	(0.003)
Any Event	0.262	(0.190)
Seasonal	0.008***	(0.001)
Trend	0.007***	(0.003)
O ₃ : Any Event	-0.005	(0.007)
Constant	4.036***	(0.337)

-Total effect models Cardiovascular mortality:

Table 13:(Total effects model for PM₁₀ during Covid Year) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
PM ₁₀ COVID Year	-0.012**	(0.006)
PM ₁₀ not COVID Year	0.001	(0.003)
COVID Year	0.420	(0.279)
Seasonal	0.005***	(0.002)
Trend	0.010***	(0.001)
Hajj Events	0.073	(0.045)
Constant	3.625***	(0.191)

Table 14:(Total effects model for PM₁₀ during Hajj Events) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
PM ₁₀ Hajj Events	-0.017**	(0.008)
PM ₁₀ not Hajj Events	-0.001	(0.003)
COVID Year	-0.145***	(0.044)
Seasonal	0.004***	(0.002)
Trend	0.011***	(0.001)
Hajj Events	0.911**	(0.428)
Constant	3.736***	(0.187)

Table 15:(Total effects model for PM₁₀ during Any Event) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
PM ₁₀ Any Event	-0.003	(0.003)
PM ₁₀ not Any Event	-0.001	(0.003)
COVID Year	-0.046	(0.081)
Seasonal	0.005***	(0.002)
Trend	0.011***	(0.001)
Hajj Events	0.168**	(0.085)
Constant	3.706***	(0.187)

Table 16:(Total effects model for NO₂ during Covid Year) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
NO ₂ COVID Year	0.011	(0.008)
NO ₂ not COVID Year	0.008**	(0.004)
COVID Year	-0.176	(0.185)
Seasonal	0.005***	(0.002)
Trend	0.011***	(0.001)
Hajj Events	0.070*	(0.041)
Constant	3.483***	(0.128)

Table 17:(Total effects model for NO₂ during Hajj Events) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
NO ₂ Hajj Events	0.034**	(0.013)
NO ₂ not Hajj Events	0.007*	(0.004)
COVID Year	-0.125***	(0.038)
Seasonal	0.004**	(0.002)
Trend	0.010***	(0.001)
Hajj Events	-0.440*	(0.261)
Constant	3.580***	(0.134)

Table 18:(Total effects model for NO₂ during Any Event) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
NO ₂ Any Event	0.012**	(0.005)
NO ₂ not Any Event	0.008**	(0.004)
COVID Year	-0.191**	(0.091)
Seasonal	0.005***	(0.002)
Trend	0.011***	(0.001)
Hajj Events	0.018	(0.077)
Constant	3.481***	(0.123)

Table 19:(Total effects model for SO₂ during Covid Year) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
SO ₂ COVID Year	0.008***	(0.002)
SO ₂ not COVID Year	-0.003***	(0.001)
COVID Year	-0.586***	(0.081)
Seasonal	0.005***	(0.002)
Trend	0.011***	(0.001)
Hajj Events	0.096**	(0.041)
Constant	3.779***	(0.115)

Table 20:(Total effects model for SO₂ during Hajj Events) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
SO ₂ Hajj Events	-0.006***	(0.002)
SO ₂ not Hajj Events	-0.001	(0.001)
COVID Year	-0.151***	(0.042)
Seasonal	0.003*	(0.002)
Trend	0.010***	(0.001)
Hajj Events	0.383***	(0.102)
Constant	3.786***	(0.117)

Table 21:(Total effects model for SO₂ during Any Event) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
SO ₂ Any Event	-0.0004	(0.001)
SO ₂ not Any Event	-0.002***	(0.001)
COVID Year	-0.215***	(0.057)
Seasonal	0.006***	(0.002)
Trend	0.011***	(0.001)
Hajj Events	-0.008	(0.064)
Constant	3.704***	(0.115)

Table 22:(Total effects model for O₃ during Covid Year) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
O ₃ COVID Year	0.002	(0.008)
O ₃ not COVID Year	0.003	(0.003)
COVID Year	-0.105	(0.217)
Seasonal	0.005***	(0.002)
Trend	0.011***	(0.001)
Hajj Events	0.056	(0.041)
Constant	3.567***	(0.120)

Table 23:(Total effects model for O₃ during Hajj Events) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
O ₃ Hajj Events	0.046***	(0.016)
O ₃ not Hajj Events	0.001	(0.003)
COVID Year	-0.109***	(0.041)
Seasonal	0.004***	(0.002)
Trend	0.010***	(0.001)
Hajj Events	-1.083**	(0.421)
Constant	3.652***	(0.124)

Table 24:(Total effects model for O₃ during Any Event) Poisson regression model for Cardiovascular Mortality.

Variable	Coefficient	Standard Error
O ₃ Any Event	0.003	(0.003)
O ₃ not Any Event	0.003	(0.003)
COVID Year	-0.132	(0.082)
Seasonal	0.005***	(0.002)
Trend	0.011***	(0.001)
Hajj Events	0.059	(0.072)
Constant	3.566***	(0.120)

3- Respiratory mortality models:

-Interaction effect models for Respiratory mortality:

Table 1: (Effect modification model for PM₁₀ during COVID Year) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Std Error
PM ₁₀	-0.006	0.004
COVID Year	1.794***	0.347
Seasonal	0.014***	0.001
Trend	0.031***	0.007
Hajj Events	0.152***	0.057
PM ₁₀ : COVID Year Interaction	-0.032***	0.008
Constant	2.353***	0.436

Table 2: (Effect modification model for PM₁₀ during Hajj Events) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Std Error
PM ₁₀	-0.014***	0.004
Hajj Events	1.372***	0.482
Seasonal	0.013***	0.001
Trend	0.040***	0.006
COVID Year	0.409***	0.045
PM ₁₀ : Hajj Events	-0.023**	0.009
Constant	2.108***	0.441

Table 3:(Effect modification model for PM₁₀ during Any Event) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Std Error
PM ₁₀	0.01	0.005
Any Event	2.126***	0.280
Seasonal	0.015***	0.001
Trend	0.031***	0.006
PM ₁₀ : Any Event	-0.039***	0.006
Constant	2.045***	0.435

Table 4: (Effect modification model for NO₂ during COVID) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Std Error
NO ₂	0.013**	0.007
COVID Year	0.580**	0.238
Seasonal	0.012***	0.001
Trend	0.044***	0.008
Hajj Events	0.112**	0.053
NO ₂ : COVID Year	-0.002	0.012
Constant	0.923	0.596

Table 5:(Effect modification model for NO₂ during Hajj Events) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Std Error
NO ₂	0.008	0.006
Hajj Events	-0.692**	0.295
Seasonal	0.012***	0.001
Trend	0.044***	0.007
COVID Year	0.525***	0.034
NO ₂ : Hajj Events	0.042***	0.015
Constant	0.986*	0.554

Table 6:(Effect modification model for NO₂ during Any Event) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Std Error
NO ₂	0.005	0.007
Any Event	-0.227	0.202
Seasonal	0.011***	0.001
Trend	0.040***	0.007
NO ₂ : Any Event Interaction	0.038***	0.010
Constant	1.384**	0.574

Table 7:(Effect modification model for SO₂ during COVID) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Std Error
SO ₂	-0.003*	0.002
COVID Year	0.725***	0.108
Seasonal	0.011***	0.001
Trend	0.056***	0.010
Hajj Events	0.092*	0.052
SO ₂ : COVID Year Interaction	-0.008***	0.002
Constant	0.553	0.633

Table 8:(Effect modification model for SO₂ during Hajj Events) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Std Error
SO ₂	-0.004***	0.001
Hajj Events	0.464***	0.108
Seasonal	0.012***	0.001
Trend	0.064***	0.010
COVID Year	0.406***	0.048
SO ₂ : Hajj Events	-0.007***	0.002
Constant	0.061***	0.604

Table 9:(Effect modification model for SO₂ during Any Event) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
SO ₂	-0.001	(0.002)
Any Event	0.940***	(0.097)
Seasonal	0.012***	(0.001)
Trend	0.056***	(0.010)
SO ₂ : Any Event	-0.012***	(0.002)
Constant	0.448	(0.595)

Table 10:(Effect modification model for O₃ during COVID) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
O ₃	-0.008*	(0.004)
COVID Year	1.681***	(0.238)
Seasonal	0.013***	(0.001)
Trend	0.029***	(0.006)
Hajj Events	0.079	(0.052)
O ₃ : COVID Year	-0.043***	(0.009)
Constant	2.371***	(0.439)

Table 11: (Effect modification model for O₃ during Hajj Events) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
O ₃	-0.016***	(0.004)
Hajj Events	-1.149**	(0.562)
Seasonal	0.012***	(0.001)
Trend	0.034***	(0.006)
COVID Year	0.608***	(0.036)
O ₃ : Hajj Events	0.051**	(0.023)
Constant	2.206***	(0.448)

Table 12:(Effect modification model for O₃ during Any Event) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
O ₃	-0.008*	(0.004)
Any Event	1.125***	(0.228)
Seasonal	0.009***	(0.001)
Trend	0.025***	(0.006)
O ₃ : Any Event	-0.026	(0.009)
Constant	2.622***	(0.437)

-Total effect models for Respiratory mortality:

Table 13:(Total effects model for PM₁₀ during Covid Year) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
PM ₁₀ COVID Year	-0.038***	(0.007)
PM ₁₀ not COVID Year	-0.006	(0.004)
COVID Year	1.794***	(0.347)
Seasonal	0.014***	(0.001)
Trend	0.031***	(0.007)
Hajj Events	0.152***	(0.057)
Constant	2.353***	(0.436)

Table 14:(Total effects model for PM₁₀ during Hajj Events) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
PM ₁₀ Hajj Events	-0.037***	(0.010)
PM ₁₀ not Hajj Events	-0.014***	(0.004)
COVID Year	0.409***	(0.045)
Seasonal	0.013***	(0.001)
Trend	0.040***	(0.006)
Hajj Events	1.372***	(0.482)
Constant	2.108***	(0.441)

Table 15:(Total effects model for PM₁₀ during Any Event) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
PM ₁₀ Any Event	-0.018***	(0.004)
PM ₁₀ not Any Event	-0.013***	(0.004)
COVID Year	0.624***	(0.091)
Seasonal	0.013***	(0.001)
Trend	0.038***	(0.006)
Hajj Events	0.347***	(0.090)
Constant	2.187***	(0.437)

Table 16:(Total effects model for NO₂ during Covid Year) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
NO ₂ COVID Year	0.012	(0.010)
NO ₂ not COVID Year	0.013**	(0.007)
COVID Year	0.580**	(0.238)
Seasonal	0.012***	(0.001)
Trend	0.044***	(0.008)
Hajj Events	0.112**	(0.053)
Constant	0.923	(0.596)

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Table 17:(Total effects model for NO₂ during Hajj Events) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
NO ₂ Hajj Events	0.051***	(0.015)
NO ₂ not Hajj Events	0.008	(0.006)
COVID Year	0.525***	(0.034)
Seasonal	0.012***	(0.001)
Trend	0.044***	(0.007)
Hajj Events	-0.692**	(0.295)
Constant	0.986*	(0.544)

Table 18:(Total effects model for NO₂ during Any Event) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
NO ₂ Any Event	0.013*	(0.007)
NO ₂ not Any Event	0.013**	(0.006)
COVID Year	0.540***	(0.109)
Seasonal	0.012***	(0.001)
Trend	0.044***	(0.007)
Hajj Events	0.107	(0.092)
Constant	0.957*	(0.556)

Table 19:(Total effects model for SO₂ during Covid Year) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
SO ₂ COVID Year	-0.010***	(0.002)
SO ₂ not COVID Year	-0.003*	(0.002)
COVID Year	0.725***	(0.108)
Seasonal	0.011***	(0.001)
Trend	0.056***	(0.010)
Hajj Events	0.092*	(0.052)
Constant	0.553***	(0.633)

Table 20:(Total effects model for SO₂ during Hajj Events) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
SO ₂ Hajj Events	-0.011***	(0.002)
SO ₂ not Hajj Events	-0.004***	(0.001)
COVID Year	0.406***	(0.048)
Seasonal	0.012***	(0.001)
Trend	0.064***	(0.010)
Hajj Events	0.464***	(0.108)
Constant	0.061	(0.604)

Table 21:(Total effects model for SO₂ during Any Event) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
SO ₂ Any Event	-0.007***	(0.001)
SO ₂ not Any Event	-0.003*	(0.002)
COVID Year	0.603***	(0.069)
Seasonal	0.012***	(0.001)
Trend	0.057***	(0.010)
Hajj Events	0.314***	(0.068)
Constant	0.494	(0.621)

Table 22:(Total effects model for O₃ during Covid Year) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
O ₃ COVID Year	-0.051***	(0.009)
O ₃ not COVID Year	-0.008*	(0.004)
COVID Year	1.681***	(0.238)
Seasonal	0.013***	(0.001)
Trend	0.029***	(0.006)
Hajj Events	0.079	(0.052)
Constant	2.371***	(0.439)

Table 23:(Total effects model for O₃ during Hajj Events) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
O ₃ Hajj Events	0.035	(0.022)
O ₃ not Hajj Events	-0.016***	(0.004)
COVID Year	0.608***	(0.036)
Seasonal	0.012***	(0.001)
Trend	0.034***	(0.006)
Hajj Events	-1.149**	(0.562)
Constant	2.206***	(0.448)

Table 24:(Total effects model for O₃ during Any Event) Poisson regression model for Respiratory Mortality.

Variable	Coefficient	Standard Error
O ₃ Any Event	-0.020***	(0.004)
O ₃ not Any Event	-0.012***	(0.004)
COVID Year	0.771***	(0.090)
Seasonal	0.012***	(0.001)
Trend	0.032***	(0.006)
Hajj Events	0.244***	(0.077)
Constant	2.294***	(0.443)

4-Estimated Relative Risk (RR) of pollutants on Respiratory and Cardiovascular mortality:

Table 25: Estimated Relative Risk (RR) per interquartile range (IQR) of PM₁₀, NO₂, SO₂ and O₃ on respiratory mortality during important events.

Model	RR per IQR	2.5% CI	97.5% CI
Effect of PM10 during COVID	0.74	0.66	0.82
Effect of PM10 not during COVID	0.95	0.89	1.02
Effect of PM10 during Hajj	0.74	0.64	0.86
Effect of PM10 not during Hajj	0.89	0.84	0.95
Effect of PM10 during Any Event	0.87	0.81	0.92
Effect of PM10 not during Any Event	0.90	0.85	0.96
Effect of NO2 during COVID	1.04	0.97	1.14
Effect of NO2 not during COVID	1.06	1.00	1.12
Effect of NO2 during Any Event	1.06	0.99	1.12
Effect of NO2 not during Any Event	1.05	1.01	1.11
Effect of SO2 during COVID	0.73	0.65	0.82
Effect of SO2 not during COVID	0.92	0.84	1.01
Effect of SO2 during Hajj	0.72	0.64	0.81
Effect of SO2 not during Hajj	0.88	0.81	0.96
Effect of SO2 during Any Event	0.80	0.74	0.87
Effect of SO2 not during Any Event	0.92	0.84	1.01
Effect of O3 during COVID	0.77	0.71	0.84
Effect of O3 not during COVID	0.96	0.93	1.00
Effect of O3 during Any Event	0.90	0.87	0.94
Effect of O3 not during Any Event	0.94	0.91	0.98

Table 26: Estimated Relative Risk (RR) per interquartile range (IQR) of PM₁₀, NO₂, SO₂ and O₃ on cardiovascular mortality during important events.

Model	RR per IQR	2.5% CI	97.5% CI
Effect of PM10 during COVID	0.79	0.72	0.87
Effect of PM10 not during COVID	1.06	1.00	1.12
Effect of PM10 during Hajj	0.89	0.77	1.02
Effect of PM10 not during Hajj	0.98	0.94	1.03
Effect of PM10 during Any Event	0.96	0.92	1.02
Effect of PM10 not during Any Event	0.99	0.94	1.04
Effect of NO2 during COVID	0.99	0.92	1.07
Effect of NO2 not during COVID	1.03	1.00	1.07
Effect of NO2 during Any Event	1.03	0.99	1.08
Effect of NO2 not during Any Event	1.03	1.00	1.06
Effect of SO2 during COVID	1.22	1.11	1.34
Effect of SO2 not during COVID	0.91	0.85	0.96
Effect of SO2 during Hajj	0.84	0.76	0.94
Effect of SO2 not during Hajj	1.01	0.96	1.06
Effect of SO2 during Any Event	1.00	0.94	1.06
Effect of SO2 not during Any Event	0.97	0.91	1.03
Effect of O3 during COVID	0.89	0.83	0.96
Effect of O3 not during COVID	0.99	0.96	1.02
Effect of O3 during Any Event	0.98	0.94	1.01
Effect of O3 not during Any Event	0.98	0.95	1.00