

Supplement of Atmos. Chem. Phys., 19, 8209–8228, 2019
<https://doi.org/10.5194/acp-19-8209-2019-supplement>
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Supplement of

**Nepal Ambient Monitoring and Source Testing Experiment (NAMaSTE):
emissions of particulate matter and sulfur dioxide from vehicles and brick
kilns and their impacts on air quality in the Kathmandu Valley, Nepal**

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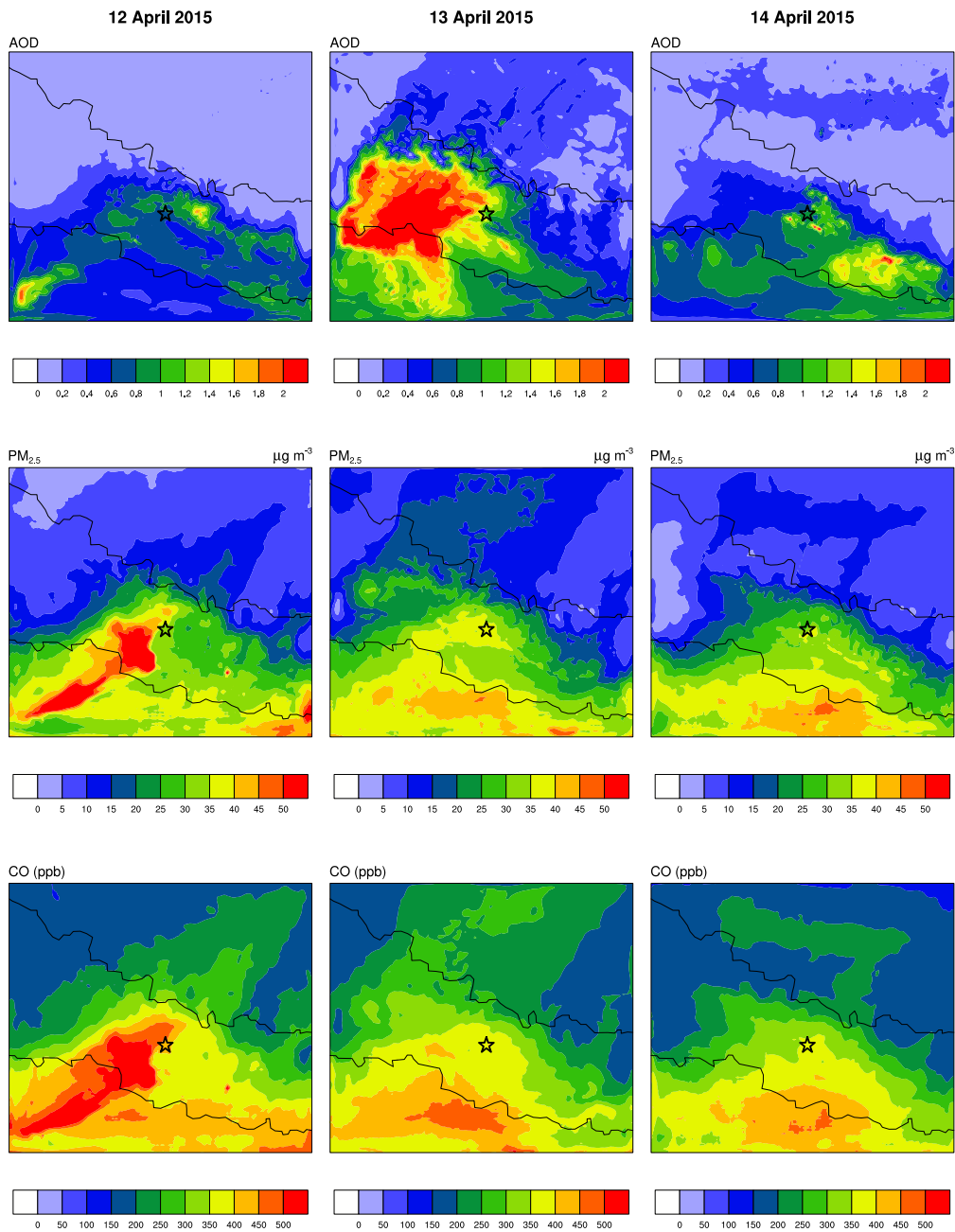


Figure S1. Simulated daily AOD, surface PM_{2.5} and CO in April 12-14, 2015. Kathmandu Valley is indicated with an open star in the figure.

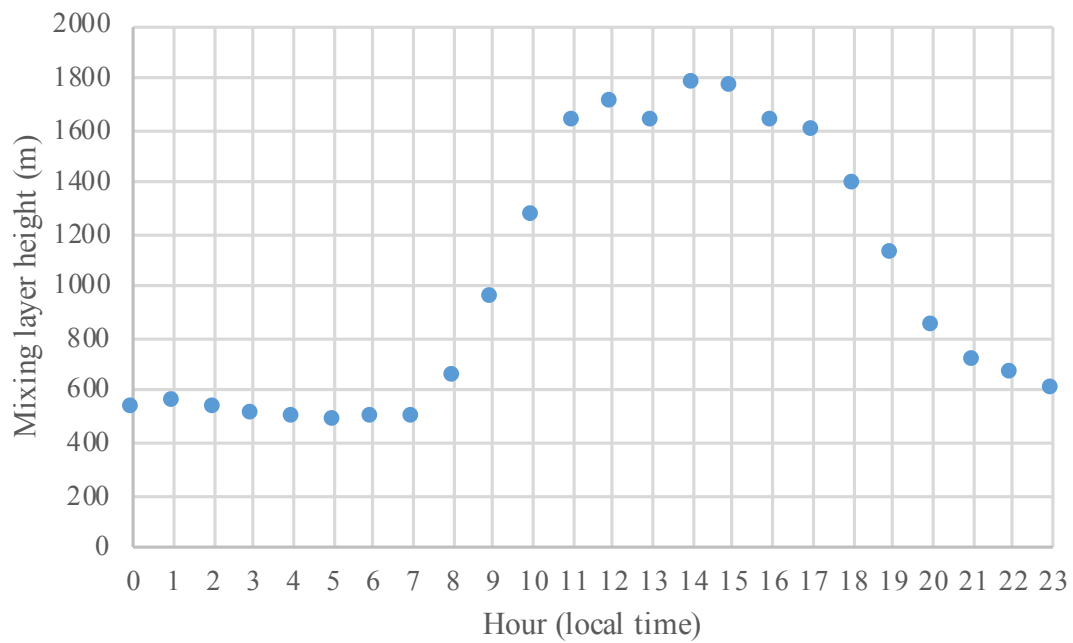


Figure S2. Averaged diurnal cycle of the mixing layer height (m) as simulated by WRF-Chem (HTAP_vehicle_brick) for the period April 12-24, 2015.

Table S1a. Vehicle technology used as IVE model inputs in 2015

Motorcycle									
Description	Fuel	Weight	Air/Fuel Control	Exhaust Control	Evaporative Control	Age	Index	Share	Corresponding Euro Standards
Small Engine	Petrol	Light	4-Cycle, Carb	None	None	>50K	1208	0.010	Pre-Euro
Small Engine	Petrol	Light	4-Cycle, Carb	Improved	None	26-50K	1216	0.010	Pre-Euro
Small Engine	Petrol	Light	4-Cycle, Carb	Improved	None	>50K	1217	0.040	Pre-Euro
Small Engine	Petrol	Medium	4-Cycle, Carb	Improved	None	26-50K	1219	0.010	Pre-Euro
Small Engine	Petrol	Medium	4-Cycle, Carb	Improved	None	>50K	1220	0.020	Pre-Euro
Small Engine	Petrol	Light	4-Cycle, Carb	High Tech	None	0-25K	1224	0.010	Euro III
Small Engine	Petrol	Light	4-Cycle, Carb	High Tech	None	26-50K	1225	0.040	Pre-Euro
Small Engine	Petrol	Light	4-Cycle, Carb	High Tech	None	>50K	1226	0.020	Pre-Euro
Small Engine	Petrol	Medium	4-Cycle, Carb	High Tech	None	0-25K	1227	0.030	Euro III
Small Engine	Petrol	Medium	4-Cycle, Carb	High Tech	None	26-50K	1228	0.030	Euro III
Small Engine	Petrol	Medium	4-Cycle, Carb	High Tech	None	>50K	1229	0.040	Pre-Euro
Small Engine	Petrol	Light	4-Cycle, Carb	Catalyst	None	0-25K	1233	0.020	Euro III
Small Engine	Petrol	Light	4-Cycle, Carb	Catalyst	None	26-50K	1234	0.030	Euro III
Small Engine	Petrol	Light	4-Cycle, Carb	Catalyst	None	>50K	1235	0.010	Pre-Euro
Small Engine	Petrol	Medium	4-Cycle, Carb	Catalyst	None	0-25K	1236	0.450	Euro III
Small Engine	Petrol	Medium	4-Cycle, Carb	Catalyst	None	26-50K	1237	0.110	Euro III
Small Engine	Petrol	Medium	4-Cycle, Carb	Catalyst	None	>50K	1238	0.040	Pre-Euro
Small Engine	Petrol	Medium	4-Cycle, FI	Catalyst	PCV	0-25K	1245	0.070	Euro III
Small Engine	Petrol	Medium	4-Cycle, FI	Catalyst	PCV	26-50K	1246	0.010	Pre-Euro

Bus/Mini bus									
Truck/Bus	Diesel	Heavy	Pre-Chamber Injection	None	None	>161K km	1079	0.100	Pre-Euro
Truck/Bus	Diesel	Heavy	Direct Injection	EGR+Improved	None	80-161K km	1096	0.010	Pre-Euro
Truck/Bus	Diesel	Heavy	Direct Injection	EGR+Improved	None	>161K km	1097	0.010	Pre-Euro
Truck/Bus	Diesel	Heavy	FI	Particulate/NOx	None	80-161K km	1114	0.010	Pre-Euro
Truck/Bus	Diesel	Heavy	FI	Particulate/NOx	None	>161K km 1115	0.050	Pre-Euro	
Truck/Bus	Diesel	Heavy	FI	EuroI	None	<79K km	1122	0.010	Euro I
Truck/Bus	Diesel	Heavy	FI	EuroI	None	80-161K km	1123	0.020	Euro I
Truck/Bus	Diesel	Heavy	FI	EuroI	None	>161K km	1124	0.190	Euro I
Truck/Bus	Diesel	Heavy	FI	EuroII	None	<79K km	1131	0.320	Euro II
Truck/Bus	Diesel	Heavy	FI	EuroII	None	80-161K km	1132	0.100	Euro II
Truck/Bus	Diesel	Heavy	FI	EuroII	None	>161K km	1133	0.180	Euro II

Taxi									
Auto/Small Truck	Petrol	Light	Multi-Pt FI	none	PCV	80-161K km	100	0.03	Pre-Euro
Auto/Small Truck	Petrol	Light	Multi-Pt FI	none	PCV	>161K km	101	0.28	Pre-Euro
Auto/Small Truck	Petrol	Light	Multi-Pt FI	EuroI	PCV/Tank	<79K km	171	0.04	Euro I
Auto/Small Truck	Petrol	Light	Multi-Pt FI	EuroI	PCV/Tank	80-161K km	172	0.11	Euro I
Auto/Small Truck	Petrol	Light	Multi-Pt FI	EuroI	PCV/Tank	>161K km	173	0.45	Euro I
Auto/Small Truck	Petrol	Light	Multi-Pt FI	EuroII	PCV/Tank	<79K km	180	0.04	Euro II
Auto/Small Truck	Petrol	Light	Multi-Pt FI	EuroII	PCV/Tank	80-161K km	181	0.02	Euro II
Auto/Small Truck	Petrol	Light	Multi-Pt FI	EuroII	PCV/Tank	>161K km	182	0.03	Euro II

Table S1b. Vehicle technology used as IVE model inputs in 2015

Car/Pickup									
Auto/Small Truck	Petrol	Medium	Carburetor	2-Way	PCV	<79K km	12	0.004	Euro I
Auto/Small Truck	Petrol	Light	Carburetor	3-Way	PCV	<79K km	27	0.006	Euro I
Auto/Small Truck	Petrol	Medium	Carburetor	3-Way	PCV	<79K km	30	0.003	Euro I
Auto/Small Truck	Petrol	Light	Single-Pt FI	2-Way	PCV	<79K km	63	0.325	Euro I
Auto/Small Truck	Petrol	Light	Single-Pt FI	2-Way	PCV	80-161K km	64	0.013	Euro I
Auto/Small Truck	Petrol	Medium	Single-Pt FI	2-Way	PCV	<79K km	66	0.029	Euro I
Auto/Small Truck	Petrol	Light	Multi-Pt FI	3-Way	PCV	<79K km	117	0.120	Euro II
Auto/Small Truck	Petrol	Medium	Multi-Pt FI	3-Way	PCV	<79K km	120	0.052	Euro II
Auto/Small Truck	Propane	Light	Carb/Mixer	None	PCV	<79K km	396	0.006	Pre-Euro
Auto/Small Truck	Propane	Light	Carb/Mixer	None	PCV	80-161K km	397	0.003	Pre-Euro
Auto/Small Truck	Propane	Light	Carb/Mixer	3-Way	PCV	<79K km	423	0.003	Euro I
Auto/Small Truck	Diesel	Light	Pre-Chamber Inject.	Improved	None	<79K km	747	0.198	Euro I
Auto/Small Truck	Diesel	Light	Pre-Chamber Inject.	Improved	None	80-161K km	748	0.016	Euro I
Auto/Small Truck	Diesel	Light	Pre-Chamber Inject.	Improved	None	>161K km	749	0.003	Euro I
Auto/Small Truck	Diesel	Medium	Pre-Chamber Inject.	Improved	None	<79K km	750	0.094	Euro I
Auto/Small Truck	Diesel	Medium	Pre-Chamber Inject.	Improved	None	80-161K km	751	0.071	Euro I
Auto/Small Truck	Diesel	Medium	Pre-Chamber Inject.	Improved	None	>161K km	752	0.026	Euro I
Auto/Small Truck	Diesel	Heavy	Pre-Chamber Inject.	Improved	None	<79K km	753	0.023	Euro I
Auto/Small Truck	Diesel	Heavy	Pre-Chamber Inject.	Improved	None	>161K km	755	0.003	Euro I
Van/Jeep									
Auto/Small Truck	Diesel	Medium	Direct Injection	EGR+Improved	None	>161K km	761	0.02	Pre-Euro
Auto/Small Truck	Diesel	Medium	FI	EuroI	None	<79K km	786	0.02	Euro I
Auto/Small Truck	Diesel	Medium	FI	EuroI	None	80-161K km	787	0.01	Euro I
Auto/Small Truck	Diesel	Medium	FI	EuroI	None	>161K km	78	0.92	Euro I
Auto/Small Truck	Diesel	Heavy	FI	EuroI	None	<79K km	789	0.03	Euro I
3-Wheeler									
Small Engine	CNG/LPG	Heavy	4-Cycle, Carb	Catalyst	None	26-50K	1276	0.02	Pre-Euro
Small Engine	CNG/LPG	Heavy	4-Cycle, Carb	Catalyst	None	>50K	1277	0.98	Pre-Euro
Truck/Mini truck									
Truck/Bus	Diesel	Light	Pre-Chamber Inject.	None	None	>161K km	1073	0.09605	Pre-Euro
Truck/Bus	Diesel	Medium	Pre-Chamber Inject.	None	None	>161K km	1076	0.08145	Pre-Euro
Truck/Bus	Diesel	Heavy	Pre-Chamber Inject.	None	None	>161K km	1079	0.1775	Pre-Euro
Truck/Bus	Diesel	Light	Direct Injection	Improved	None	>161K km	1082	0.10275	Pre-Euro
Truck/Bus	Diesel	Medium	Direct Injection	Improved	None	>161K km	1085	0.08715	Pre-Euro
Truck/Bus	Diesel	Heavy	Direct Injection	Improved	None	>161K km	1088	0.1899	Pre-Euro
Truck/Bus	Diesel	Light	FI	Euro I	None	>161K km	1118	0.04135	Euro I
Truck/Bus	Diesel	Medium	FI	Euro I	None	>161K km	1121	0.03505	Euro I
Truck/Bus	Diesel	Heavy	FI	Euro I	None	>161K km	1124	0.0764	Euro I
Truck/Bus	Diesel	Light	FI	Euro II	None	80-161K km	1126	0.0304	Euro II
Truck/Bus	Diesel	Medium	FI	Euro II	None	80-161K km	1129	0.0258	Euro II
Truck/Bus	Diesel	Heavy	FI	Euro II	None	80-161K km	1132	0.0562	Euro II

Table S2. Parameters used for estimating fuel consumption for each type of brick kiln in the Kathmandu Valley

Type of Kilns	Number of Kilns	Annual average production ^a (bricks/plant/year)	Monthly average production ^b P _j , (bricks/plant/month)	Average weight of a brick ^c W _{brick} (kg per brick)	Specific energy consumption ^d E _{brick} (MJ/kg-brick)	Specific energy density of coal U _{coal} , (MJ/kg-coal)	Coal consumed BK _j , kg-coal/plant/month
FCBTK	46	5719626	953271	2.03	1.30	27	93173
Hoffman	2	20000000	3333333	2.03	1.36	27	340840
VSBK	1	8000000	1333333	2.03	0.80	27	80198
Zigzag	63	5719626	953271	2.03	1.03	27	73822

a: The annual average production of each type of kiln is obtained from <http://doenv.gov.np/files/download/Report%20Brick%20Kiln%20%20Emission.pdf>;

b: Nepal brick kilns usually operate 6 months per year, running from December to May;

c: Brick weight in Kathmandu Valley is 2.03 kg on average (CEN, 2009);

d. The value of specific energy consumption is obtained from <http://www.ccacoalition.org/en/resources/factsheets-about-brick-kilns-south-and-south-east-a>

Table S3a. Emission factors (g/kg fuel) for a zigzag kiln

Compound (Formula)	Emission factors	Reference
EC	0.1118	Jayarathne et al. (2018)
OC	1.0577	
SO ₄	4.8201	
PM _{2.5}	15.11	
Sulfur Dioxide (SO ₂)	12.7	Stockwell et al. (2016)
Nitric Oxide (NO)	1.28	
Nitrogen Dioxide (NO ₂)	8.21×10^{-2}	
Acetylene (C ₂ H ₂)	1.65×10^{-2}	
Ethylene (C ₂ H ₄)	4.32×10^{-2}	
Propylene (C ₃ H ₆)	6.58×10^{-2}	
Methanol (CH ₃ OH)	0.112	
Formic Acid (HCOOH)	5.84×10^{-2}	
Acetic Acid (CH ₃ COOH)	0.471	
Phenol (C ₆ H ₅ OH)	1.54×10^{-2}	
1,3-Butadiene (C ₄ H ₆)	1.51×10^{-2}	
Isoprene (C ₅ H ₈)	2.46×10^{-2}	
Nitrous Acid (HONO)	4.45×10^{-2}	
Methyl iodide (CH ₃ I)	2.01×10^{-3}	
1,2-Dichloroethene (C ₂ H ₂ Cl ₂)	4.45×10^{-5}	
Methyl nitrate (CH ₃ NO ₃)	2.92×10^{-3}	
Ethane (C ₂ H ₆)	2.06×10^{-3}	
Propane (C ₃ H ₈)	1.97×10^{-3}	
i-Butane (C ₄ H ₁₀)	1.60×10^{-3}	
n-Butane (C ₄ H ₁₀)	1.92×10^{-3}	
1-Butene (C ₄ H ₈)	1.68×10^{-3}	
i-Butene (C ₄ H ₈)	1.47×10^{-3}	
trans-2-Butene (C ₄ H ₈)	1.44×10^{-3}	
cis-2-Butene (C ₄ H ₈)	9.65×10^{-4}	
i-Pentane (C ₅ H ₁₂)	3.70×10^{-2}	
n-Pentane (C ₅ H ₁₂)	3.26×10^{-2}	
1-Pentene (C ₅ H ₁₀)	1.60×10^{-3}	
trans-2-Pentene (C ₅ H ₁₀)	2.64×10^{-2}	
cis-2-Pentene (C ₅ H ₁₀)	9.01×10^{-4}	
3-Methyl-1-butene (C ₅ H ₁₀)	3.32×10^{-4}	
1,2-Propadiene (C ₃ H ₄)	2.15×10^{-5}	
n-Hexane (C ₆ H ₁₄)	2.16×10^{-2}	
n-Heptane (C ₇ H ₁₆)	3.04×10^{-3}	

Table S3b. Emission factors (g/kg fuel) for a zigzag kiln

Compound (Formula)	Emission factors	Reference
n-Octane (C ₈ H ₁₈)	1.58×10^{-3}	Stockwell et al. (2016)
n-Nonane (C ₉ H ₂₀)	2.42×10^{-3}	
n-Decane (C ₁₀ H ₂₂)	2.02×10^{-3}	
2,3-Dimethylbutane (C ₆ H ₁₄)	3.59×10^{-3}	
2-Methylpentane (C ₆ H ₁₄)	4.84×10^{-3}	
3-Methylpentane (C ₆ H ₁₄)	1.17×10^{-2}	
2,2,4-Trimethylpentane (C ₈ H ₁₈)	8.53×10^{-4}	
Cyclopentane (C ₅ H ₁₀)	8.53×10^{-4}	
Cyclohexane (C ₆ H ₁₂)	2.98×10^{-3}	
Benzene (C ₆ H ₆)	8.25×10^{-3}	
Toluene (C ₇ H ₈)	2.80×10^{-2}	
Ethylbenzene (C ₈ H ₁₀)	1.35×10^{-2}	
m/p-Xylene (C ₈ H ₁₀)	5.74×10^{-2}	
o-Xylene (C ₈ H ₁₀)	2.18×10^{-2}	
Styrene (C ₈ H ₈)	4.56×10^{-3}	
i-Propylbenzene (C ₉ H ₁₂)	4.07×10^{-4}	
n-Propylbenzene (C ₉ H ₁₂)	1.82×10^{-3}	
3-Ethyltoluene (C ₉ H ₁₂)	6.93×10^{-3}	
4-Ethyltoluene (C ₉ H ₁₂)	3.69×10^{-3}	
2-Ethyltoluene (C ₉ H ₁₂)	2.30×10^{-3}	
1,3,5-Trimethylbenzene (C ₉ H ₁₂)	4.30×10^{-3}	
1,2,4-Trimethylbenzene (C ₉ H ₁₂)	5.59×10^{-3}	
1,2,3-Trimethylbenzene (C ₉ H ₁₂)	2.03×10^{-3}	
alpha-Pinene (C ₁₀ H ₁₆)	1.49×10^{-3}	
beta-Pinene (C ₁₀ H ₁₆)	1.31×10^{-3}	
Ethanol (C ₂ H ₆ O)	4.84×10^{-3}	
Acetaldehyde (C ₂ H ₄ O)	6.94×10^{-2}	
Acetone (C ₃ H ₆ O)	1.46×10^{-1}	
Butanal (C ₄ H ₈ O)	2.19×10^{-3}	
Butanone (C ₄ H ₈ O)	2.29×10^{-3}	

Table S4. Composite emission factors of different vehicle types during running in the Kathmandu Valley, April 2015 (g/km)

Vehicle types	CO	SO ₂	NO _x	NMVOC	PM
Motorcycle	7.78	0.01	0.20	2.21	0.11
Bus/Minibus	17.46	0.22	33.57	5.16	9.38
Taxi	37.72	0.04	1.61	4.69	0.01
Car/Pickup	3.72	0.06	2.47	0.77	0.28
Van/Jeep	3.97	0.14	4.51	0.62	1.03
3-wheeler	6.86	3.14E-04	0.26	0.21	0.01
Truck/Mini truck	99.79	0.80	151.85	20.44	46.49

Table S5. Composite emission factors of different vehicle types during start-up in Kathmandu Valley, April 2015 (g/start)

Vehicle types	CO	SO ₂	NO _x	NMVOC	PM
Motorcycle	9.11	0.00	1.91	1.91	0.12
Bus/Minibus	0.77	0.00	0.07	0.07	2.91
Taxi	27.60	0.00	3.07	3.07	0.01
Car/Pickup	6.20	0.00	0.51	0.51	0.11
Van/Jeep	1.93	0.00	0.15	0.15	0.27
3-wheeler	4.00	3.92E-06	0.10	0.10	0.00
Truck/Mini truck	3.90	0.01	0.29	0.29	15.51

Table S6. Total daytime rainfall (mm) and average wind speed from 9:00 am - 18:00 pm during two episode periods.

Date	15-Apr	16-Apr	18-Apr	19-Apr	20-Apr	21-Apr
Rainfall (mm)	6.4	0	19.0	0	0	6.4
Wind speed (m/s)	1.5	2.4	2.3	2.7	3.9	4.3