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# Strategies of method selection for fine-scale $PM_{2.5}$ mapping in an intra-urban area using crowdsourced monitoring

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## S1. Data and methods

### S1.1 Measurement instrument

The relationship between RH and the ratio of laser monitor measurements to the national instrument measurements for two evaluation periods was presented in the Supporting Information as Fig. S2a and Fig. S2b. The ratio of the ratio of laser air quality monitor measured hourly $PM_{2.5}$ concentrations to the national monitoring instrument measured hourly $PM_{2.5}$ concentrations (Y-axis) roughly increased exponentially with the increase in the relative humidity (RH, X-axis) for December 20–22 ($R^2$=0.2186), while the ratio was uncorrelated with RH for December 29–31 ($R^2$=0.0457). When RH correction is made by empirical equation for December 20–22, the $R^2$ between hourly $PM_{2.5}$ concentration from laser monitor measurements and the national instrument measurements improved from 0.89 to 0.9.

## S2. Results and Supplemental Analyses

### S2.1 Model fitting of LUR

Table S2 shows the predictor variables for LUR models. All of the predictors listed in this table reveals statistical significance with very small p-values (<0.05). Clearly, models of two periods shared common predictor variables of the percentage of high-density residential area (H-Resi), other built-up area (O-Built), low-density forest (L-For), stacked substance area (Sta), natural bare surfaces (Bare), and crush stampede yard area (Yard). However, the optimal buffering sizes for some of these predictors were different. For example, the optimal buffering size for H-Resi of light-polluted period was 200m, while that of heavy-polluted period was 50m. Meteorological factors of wind speed, atmospheric pressure, relative humidity, and temperature were important predictors for LUR models.

Table S3 summarizes the model fitting results for LUR models. The fitting adjusted $R^2$ ranged from 0.38 (12:00) to 0.61 (8:00) for Period 1, and from 0.25 (17:00) to 0.36 (16:00) for Period 2. The AIC values for two periods were found to be lowest at 8:00 (1400.64) and 16:00 (907.38) respectively. And the highest and lowest RMSE were 11.79 and 10.39 for Period 1, and 17.53 and 11.51 for Period 2.

### S2.2 Model performance for OK, LUR and UK

Average and standard deviation of RMSE and MRE between the observed and predicted concentrations of $PM_{2.5}$ in hold-out validation presented in Supporting Information (Table S4–S5) further demonstrated the better performance yet larger variation of these three methods with larger training data sets in $PM_{2.5}$ concentration estimation. The average RMSE and MRE of OK and UK were close and significantly smaller than LUR. Meanwhile, those of OK were generally smaller than UK in Period 1 while cases in Period 2 were the opposite.

For period 1, the RMSE (Mean±SD) of OK, LUR and UK ranged from (6.26±1.45) (10:00, n=184) to (12.54±0.83) (12:00, n=41), (11.25±1.59) (11:00, n=187) to (24.05±9.97) (8:00, n=36), and (8.65±1.07) (11:00, n=166) to (12.29±0.52) (8:00, n=36), respectively. Correspondingly, the MRE of OK, LUR and

UK increased from (6.81±1.55)% (10:00, n=184) to (13.11±1.41)% (8:00, n=36), (13±2.26)% (12:00, n=186) to (24.65±6.31)% (8:00, n=36), and (9.66±1.53)% (11:00, n=166) to (12.79±0.94)% (8:00, n=36), respectively.

For period 2, the lowest and highest values of RMSE were (9.82±3.27) (14:00, n=94) and (21.12±1.88) (18:00, n=32), (13.32±2.86) (16:00, n=103) and (44.59±10.55) (18:00, n=32), (8.70±2.20) (14:00, n=94) and (18.84±1.56) (18:00, n=32). The associated MRE were (4.36±1.25)% (14:00, n=94) and (8.80±1.19)% (18:00, n=32), (6.62±2.17)% (14:00, n=106) and (18.93±4.26)% (18:00, n=32), (4.11±1.03)% (14:00, n=94) and (8.42±0.90)% (8:00, n=36) (18:00, n=32).

**Table S1.** Predictor variables for LUR models

| Time | N | Predictor variables |
|---|---|---|
| 8:00 | 179 | H-Resi(200) + L-Resi(500) + L-For(500) + O-Built(1000) + Bare(1000) + WS + PS + RH |
| 9:00 | 207 | H-Resi(200) + L-Resi(500) + L-For(500) + Sta(1000) + Bare(1000) + Yard(500) + PS + Temp |
| 10:00 | 205 | H-Resi(300) + L-Resi(200) + L-For(500) + Cons(300) + Bare(300) + Yard(500) + PS + Temp |
| 11:00 | 208 | H-Resi(200) + L-Resi(500) + O-Built(1000) + Cons(1000) + Yard(500) + WS + RH + Temp |
| 12:00 | 207 | L-Resi(500) + O-Built(1000) + Agri(200) + Indus(1000) + Yard(500) + Dust(1000) + PS + RH |
| 14:00 | 118 | H-Resi(50) + Green(1000) + L-For(300) + Sta(1000) + Bare(200) + Yard(1000) + PS + Temp |
| 15:00 | 117 | Green(1000) + Sta(1000) + Cons(1000) + Bare(100) + Dust(1000) + PS + RH |
| 16:00 | 114 | Green(1000) + Road(1000) + Sta(500) + Bare(1000) + WS + RH + Temp |
| 17:00 | 116 | H-Resi(100) + L-For(300) + Sta(1000) + Dust(1000) + WS |
| 18:00 | 105 | H-For(1000) + Cons(50) + Bare(1000) + WS + Temp |

Significant with $p < 0.05$; N is the total amount of the records in compared pairs; H-Resi = high-density residential area; L-Resi = low-density residential area; Green = urban green land; O-Built = other built-up area; H-For = high-density forest; L-For = low-density forest, Agri = agricultural land; Sta = stacked substance; Cons = construction site; Bare = natural bare surfaces; Yard = crush stampede yard; Dust = Ground dust surface; Road = Road density; Indus = POI density including industrial and mining enterprises; (*x*) represent area proportion/ density within the *x* m buffering radius. WS = Average wind speed Atmospheric pressure; RH = Relative humidity; Temp = Temperature.

**Table S2.** Model fitting results for LUR models

| | Adjusted $R^2$ | AIC | RMSE |
|---|---|---|---|
| 8:00 | 0.61 | 1400.64 | 11.44 |
| 9:00 | 0.50 | 1628.61 | 11.79 |
| 10:00 | 0.41 | 1610.10 | 11.69 |
| 11:00 | 0.42 | 1583.87 | 10.39 |
| 12:00 | 0.38 | 1607.56 | 11.20 |
| 14:00 | 0.31 | 931.46 | 11.51 |
| 15:00 | 0.32 | 951.70 | 12.97 |
| 16:00 | 0.36 | 907.38 | 11.86 |
| 17:00 | 0.25 | 985.91 | 15.96 |
| 18:00 | 0.30 | 913.41 | 17.53 |

**Table S3.** Mean and standard deviation (SD) of root-mean-square-errors (RMSE) between observed and estimated $PM_{2.5}$ concentration

| | | 8:00 | | 9:00 | | 10:00 | | 11:00 | | 12:00 | | 14:00 | | 15:00 | | 16:00 | | 17:00 | | 18:00 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 20 | OK | 12.29 | 1.11 | 11.30 | 0.94 | 10.42 | 0.81 | 9.88 | 0.65 | 12.54 | 0.83 | | | | | | | | | | |
| | LUR | 24.05 | 9.97 | 19.11 | 4.75 | 20.33 | 5.35 | 18.82 | 10.31 | 19.40 | 4.77 | | | | | | | | | | |
| | UK | 11.44 | 0.78 | 11.03 | 0.50 | 10.67 | 0.70 | 9.76 | 0.56 | 11.13 | 0.45 | | | | | | | | | | |
| 30 | OK | 11.75 | 0.79 | 10.60 | 0.83 | 9.78 | 0.82 | 9.36 | 0.66 | 12.06 | 0.88 | 13.18 | 2.11 | 14.30 | 2.18 | 12.92 | 1.32 | 17.15 | 2.35 | 21.12 | 1.88 |
| | LUR | 17.03 | 3.39 | 15.22 | 4.39 | 15.57 | 2.30 | 14.45 | 5.32 | 15.37 | 2.90 | 29.92 | 17.26 | 26.61 | 6.71 | 27.18 | 9.74 | 35.27 | 22.10 | 44.59 | 10.55 |
| | UK | 12.29 | 0.52 | 10.75 | 0.57 | 10.26 | 0.51 | 9.68 | 0.51 | 11.07 | 0.48 | 11.42 | 1.31 | 13.09 | 1.14 | 13.02 | 1.04 | 16.16 | 1.87 | 18.84 | 1.56 |
| 40 | OK | 11.25 | 1.05 | 10.10 | 1.01 | 9.19 | 0.93 | 8.72 | 0.55 | 11.74 | 1.19 | 12.82 | 2.36 | 13.13 | 2.40 | 11.71 | 1.61 | 16.97 | 2.97 | 20.11 | 1.71 |
| | LUR | 14.88 | 1.82 | 13.33 | 1.14 | 14.97 | 2.64 | 12.65 | 1.07 | 14.01 | 1.50 | 22.09 | 9.48 | 20.95 | 3.97 | 19.74 | 5.31 | 23.69 | 8.53 | 31.99 | 6.83 |
| | UK | 12.11 | 0.70 | 10.48 | 0.61 | 10.16 | 0.66 | 9.22 | 0.51 | 11.06 | 0.53 | 11.26 | 1.42 | 12.32 | 1.58 | 12.00 | 1.17 | 15.70 | 2.24 | 18.30 | 1.69 |
| 50 | OK | 10.84 | 1.23 | 9.69 | 1.22 | 8.72 | 0.95 | 8.64 | 0.72 | 11.52 | 1.18 | 11.33 | 2.47 | 12.55 | 2.43 | 11.38 | 1.91 | 16.02 | 2.93 | 18.87 | 2.25 |
| | LUR | 14.47 | 2.58 | 12.94 | 1.23 | 13.73 | 2.16 | 12.20 | 1.01 | 13.23 | 1.01 | 17.46 | 2.98 | 19.10 | 3.12 | 15.90 | 3.06 | 21.76 | 4.90 | 27.56 | 5.63 |
| | UK | 10.66 | 0.68 | 10.48 | 0.78 | 9.95 | 0.76 | 9.32 | 0.60 | 11.03 | 0.66 | 10.54 | 1.66 | 11.87 | 1.58 | 11.70 | 1.47 | 15.22 | 2.30 | 16.74 | 2.13 |
| 60 | OK | 10.52 | 1.54 | 9.12 | 1.31 | 7.91 | 1.16 | 8.02 | 0.79 | 11.13 | 1.41 | 11.60 | 2.44 | 14.29 | 18.26 | 11.11 | 1.97 | 15.01 | 3.26 | 17.56 | 2.74 |
| | LUR | 13.70 | 1.70 | 12.55 | 1.22 | 12.91 | 1.14 | 11.61 | 1.08 | 12.87 | 1.10 | 19.95 | 13.42 | 17.95 | 2.81 | 15.48 | 2.56 | 19.50 | 3.56 | 23.98 | 3.98 |
| | UK | 10.46 | 0.86 | 10.14 | 0.83 | 9.59 | 0.82 | 8.96 | 0.65 | 10.85 | 0.76 | 10.32 | 1.80 | 11.28 | 1.71 | 11.44 | 1.62 | 14.20 | 2.86 | 16.19 | 2.70 |
| 70 | OK | 10.52 | 1.74 | 8.36 | 1.28 | 7.47 | 1.19 | 7.69 | 0.95 | 10.53 | 1.64 | 10.93 | 3.00 | 11.26 | 3.09 | 10.55 | 2.12 | 14.78 | 4.41 | 17.42 | 3.55 |
| | LUR | 13.16 | 1.34 | 11.98 | 1.22 | 13.61 | 1.22 | 11.66 | 1.18 | 12.33 | 1.19 | 16.04 | 3.15 | 16.27 | 2.49 | 14.22 | 2.04 | 18.57 | 4.03 | 22.89 | 2.89 |
| | UK | 10.48 | 0.99 | 9.82 | 0.94 | 9.61 | 1.17 | 9.01 | 0.77 | 10.54 | 1.03 | 9.88 | 2.10 | 10.30 | 2.06 | 10.98 | 1.73 | 13.82 | 4.19 | 15.53 | 3.33 |
| 80 | OK | 9.53 | 2.03 | 8.25 | 1.63 | 7.03 | 1.43 | 7.26 | 1.23 | 10.66 | 2.29 | 9.82 | 3.27 | 11.31 | 3.53 | 10.35 | 2.36 | 13.37 | 5.47 | 16.12 | 4.26 |
| | LUR | 12.68 | 1.48 | 11.94 | 1.44 | 12.77 | 1.51 | 11.29 | 1.28 | 12.33 | 1.47 | 15.93 | 3.55 | 16.41 | 2.61 | 13.74 | 1.75 | 18.53 | 5.35 | 22.79 | 3.99 |
| | UK | 10.12 | 1.23 | 9.69 | 1.38 | 9.33 | 1.40 | 8.65 | 1.07 | 10.58 | 1.36 | 8.81 | 1.88 | 11.04 | 1.88 | 11.20 | 1.93 | 12.46 | 4.76 | 15.11 | 3.50 |
| 90 | OK | 9.65 | 3.87 | 7.73 | 2.12 | 6.26 | 1.45 | 7.30 | 1.69 | 10.16 | 2.51 | 10.16 | 3.93 | 12.49 | 4.09 | 10.38 | 3.76 | 14.21 | 6.04 | 15.59 | 7.57 |
| | LUR | 13.01 | 2.09 | 11.81 | 2.00 | 12.35 | 1.92 | 11.25 | 1.59 | 12.12 | 1.90 | 15.60 | 5.67 | 15.93 | 3.82 | 13.32 | 2.86 | 17.41 | 6.61 | 22.09 | 6.49 |
| | UK | 10.26 | 1.87 | 9.49 | 2.02 | 8.90 | 1.77 | 8.70 | 1.41 | 10.54 | 2.06 | 8.70 | 2.20 | 10.00 | 2.73 | 11.35 | 2.13 | 12.29 | 6.13 | 14.24 | 5.81 |

**Table S4.** Mean and standard deviation (SD) of mean relative error (MRE, %) between observed and estimated $PM_{2.5}$ concentration

| | | 8:00 | | 9:00 | | 10:00 | | 11:00 | | 12:00 | | 14:00 | | 15:00 | | 16:00 | | 17:00 | | 18:00 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 20 | OK | 13.11 | 1.41 | 12.37 | 1.20 | 11.50 | 1.10 | 10.99 | 0.86 | 12.09 | 1.09 | | | | | | | | | | |
| | LUR | 24.65 | 6.31 | 20.37 | 3.26 | 21.30 | 3.20 | 18.81 | 3.45 | 19.37 | 3.49 | | | | | | | | | | |
| | UK | 12.79 | 0.94 | 12.48 | 0.81 | 12.38 | 0.92 | 10.80 | 0.70 | 11.54 | 0.63 | | | | | | | | | | |
| 30 | OK | 12.50 | 1.00 | 11.48 | 1.01 | 10.58 | 0.93 | 10.32 | 0.86 | 11.56 | 0.98 | 5.56 | 0.71 | 5.98 | 0.71 | 5.65 | 0.50 | 6.71 | 0.93 | 8.80 | 1.19 |
| | LUR | 18.98 | 2.86 | 16.67 | 1.82 | 17.35 | 1.79 | 15.76 | 1.74 | 15.67 | 1.49 | 11.82 | 4.58 | 11.80 | 2.88 | 12.02 | 3.39 | 13.16 | 4.40 | 18.93 | 4.26 |
| | UK | 12.24 | 0.81 | 12.05 | 0.86 | 11.80 | 0.80 | 10.68 | 0.74 | 11.54 | 0.73 | 5.13 | 0.49 | 6.02 | 0.52 | 6.35 | 0.64 | 6.76 | 0.88 | 8.42 | 0.90 |
| 40 | OK | 11.80 | 1.17 | 10.74 | 1.11 | 9.91 | 1.12 | 9.41 | 0.71 | 11.09 | 0.96 | 5.39 | 0.82 | 5.48 | 0.74 | 5.16 | 0.64 | 6.64 | 1.17 | 8.33 | 0.99 |
| | LUR | 16.85 | 1.84 | 15.23 | 1.08 | 16.74 | 1.59 | 14.37 | 0.91 | 14.67 | 1.55 | 8.84 | 2.07 | 9.34 | 1.82 | 9.03 | 1.41 | 10.16 | 2.38 | 13.85 | 2.63 |
| | UK | 11.96 | 0.90 | 11.71 | 0.89 | 11.75 | 1.14 | 10.22 | 0.68 | 11.56 | 0.69 | 5.06 | 0.52 | 5.68 | 0.64 | 5.81 | 0.72 | 6.56 | 0.88 | 8.06 | 0.89 |
| 50 | OK | 11.16 | 1.08 | 10.25 | 1.16 | 9.33 | 1.15 | 9.23 | 0.84 | 10.60 | 0.92 | 4.77 | 0.87 | 5.29 | 0.91 | 4.95 | 0.71 | 6.12 | 0.94 | 7.59 | 0.93 |
| | LUR | 16.23 | 1.99 | 15.01 | 1.35 | 15.90 | 1.46 | 13.98 | 1.19 | 13.94 | 1.08 | 7.35 | 1.09 | 8.49 | 1.27 | 7.78 | 1.11 | 9.11 | 1.46 | 11.83 | 2.28 |
| | UK | 11.93 | 0.79 | 11.83 | 0.97 | 11.46 | 1.24 | 10.35 | 0.93 | 11.48 | 0.89 | 4.78 | 0.62 | 5.43 | 0.60 | 5.61 | 0.79 | 6.15 | 0.89 | 7.08 | 1.07 |
| 60 | OK | 10.95 | 1.43 | 9.76 | 1.32 | 8.47 | 1.14 | 8.55 | 0.96 | 10.46 | 1.14 | 4.90 | 0.87 | 6.48 | 9.81 | 4.90 | 0.81 | 5.97 | 0.96 | 7.20 | 1.19 |
| | LUR | 15.57 | 1.79 | 14.62 | 1.43 | 15.19 | 1.64 | 13.45 | 1.43 | 13.68 | 1.28 | 7.61 | 2.46 | 8.27 | 1.21 | 7.55 | 0.99 | 8.57 | 1.46 | 10.75 | 1.79 |
| | UK | 11.73 | 1.11 | 11.45 | 0.99 | 10.86 | 1.26 | 10.07 | 0.96 | 11.31 | 1.01 | 4.60 | 0.62 | 5.18 | 0.66 | 5.46 | 0.91 | 5.95 | 0.84 | 6.96 | 1.24 |
| 70 | OK | 10.52 | 1.51 | 8.89 | 1.26 | 8.14 | 1.38 | 8.16 | 1.06 | 9.82 | 1.14 | 4.66 | 1.07 | 4.78 | 1.10 | 4.65 | 0.98 | 5.89 | 1.36 | 7.16 | 1.17 |
| | LUR | 14.96 | 1.57 | 14.09 | 1.63 | 15.53 | 1.89 | 13.45 | 1.60 | 13.11 | 1.35 | 6.81 | 1.10 | 7.44 | 1.04 | 7.15 | 0.94 | 7.92 | 1.24 | 10.27 | 1.24 |
| | UK | 11.55 | 1.09 | 11.12 | 1.24 | 10.97 | 1.71 | 10.01 | 1.12 | 10.93 | 1.02 | 4.49 | 0.78 | 4.81 | 0.84 | 5.26 | 0.96 | 5.65 | 1.15 | 6.51 | 1.25 |
| 80 | OK | 10.02 | 1.83 | 8.67 | 1.64 | 7.55 | 1.48 | 7.77 | 1.27 | 9.79 | 1.24 | 4.36 | 1.25 | 4.80 | 1.48 | 4.50 | 0.91 | 5.52 | 1.83 | 6.64 | 1.61 |
| | LUR | 14.81 | 2.00 | 14.23 | 1.79 | 15.21 | 2.31 | 13.22 | 2.10 | 13.08 | 1.69 | 6.64 | 1.51 | 7.56 | 1.14 | 6.87 | 0.88 | 8.15 | 1.81 | 10.17 | 1.97 |
| | UK | 11.56 | 1.50 | 10.94 | 1.52 | 10.52 | 1.96 | 9.66 | 1.53 | 10.93 | 1.34 | 4.13 | 0.75 | 5.08 | 0.83 | 5.31 | 1.00 | 5.35 | 1.39 | 6.35 | 1.54 |
| 90 | OK | 9.91 | 3.02 | 8.20 | 2.09 | 6.81 | 1.55 | 7.54 | 1.68 | 9.79 | 1.90 | 4.57 | 1.59 | 5.34 | 1.73 | 4.80 | 1.59 | 6.22 | 2.05 | 6.24 | 2.34 |
| | LUR | 15.00 | 2.89 | 14.18 | 2.89 | 14.49 | 2.98 | 13.10 | 2.67 | 13.00 | 2.26 | 6.62 | 2.17 | 7.14 | 1.47 | 6.97 | 1.59 | 7.95 | 2.48 | 10.19 | 2.56 |
| | UK | 11.66 | 2.19 | 10.80 | 2.31 | 9.79 | 2.25 | 9.73 | 1.88 | 10.95 | 1.97 | 4.11 | 1.03 | 4.62 | 1.17 | 5.61 | 1.23 | 5.52 | 1.83 | 5.77 | 1.83 |

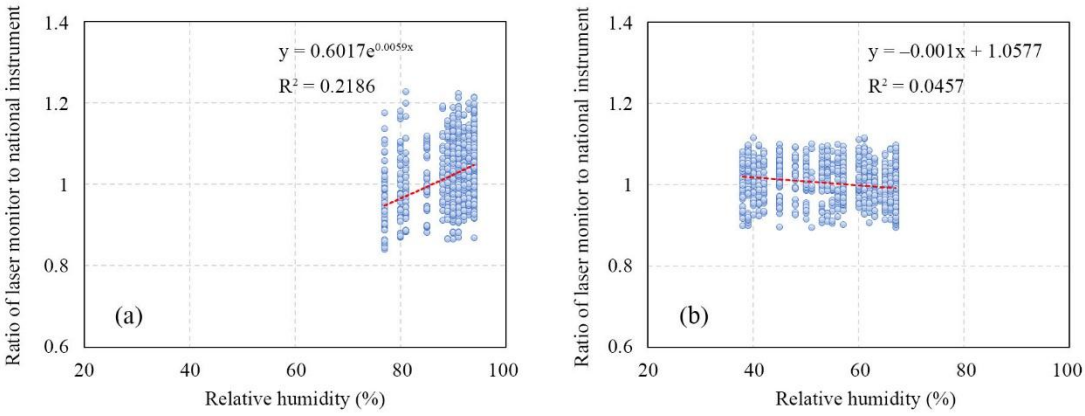


**Figure S1.** Relationship between the ratio of laser air quality monitor measured hourly $PM_{2.5}$ concentrations to the national monitoring instrument measured hourly $PM_{2.5}$ concentrations (Y-axis) and relative humidity (X-axis) for (a) December 20–22, (b) December 29–31.