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# Quantification and evaluation of atmospheric ammonia emissions with different methods: a case study for the Yangtze River Delta region, China

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# Tables

Table S1. The annual numbers of livestock and poultry by prefectural city in YRD (10 000)

| | Beef | Cow | Sow | Hog | Goat | Sheep | Layer | Laying Duck | Broiler | Meat duck | Goose | Horse | Donkey | Mule | Rabbit | Cattle | Buffalo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shanghai | 0.10 | 5.80 | 13.90 | 243.13 | 26.70 | 1.40 | 379.05 | 37.61 | 23.81 | 1051.68 | 140.00 | — | — | — | 9.60 | — | — |
| Nanjing | — | 1.75 | — | — | 11.73 | — | 491.68 | 119.51 | 12.57 | 562.96 | 108.92 | — | — | — | 17.49 | 0.01 | 1.08 |
| Wuxi | — | 0.67 | — | 74.77 | 3.67 | 0.09 | 174.87 | 42.51 | 6.31 | 282.49 | 54.65 | — | — | — | 2.23 | — | — |
| Xuzhou | — | — | — | — | 218.91 | 8.63 | 3783.84 | 919.73 | 96.01 | 4301.53 | 832.24 | 0.13 | 1.59 | 0.87 | — | — | — |
| Changzhou | 0.01 | 0.54 | 49.10 | 83.62 | 6.05 | 0.14 | 166.90 | 40.57 | 18.98 | 850.37 | 164.53 | — | — | — | — | — | — |
| Suzhou | — | 2.39 | 76.69 | 103.46 | 4.36 | 6.37 | 278.52 | 67.70 | 9.82 | 440.12 | 85.15 | — | — | — | 9.32 | — | — |
| Nantong | — | 0.75 | 270.76 | 394.71 | 227.33 | — | 2984.22 | 725.37 | 47.46 | 2126.22 | 411.37 | — | — | — | — | — | 0.32 |
| Lianyungang | 10.89 | 6.36 | 20.03 | 300.50 | 18.04 | — | 612.70 | 148.93 | 13.86 | 620.76 | 120.10 | — | 0.49 | — | — | — | — |
| Huai'an | 2.21 | 0.82 | 15.68 | 267.11 | 23.29 | — | 849.60 | 206.51 | 29.18 | 1307.15 | 252.90 | — | — | — | — | — | 3.06 |
| Yancheng | — | 1.97 | 41.79 | 735.62 | 138.68 | — | 7591.19 | 486.72 | 81.09 | 3633.09 | 702.91 | — | 0.02 | — | 228.00 | 1.38 | 1.10 |
| Yangzhou | 0.41 | 0.47 | 5.12 | 135.72 | 6.26 | — | 651.50 | 391.05 | 19.44 | 870.89 | 168.49 | — | — | — | 11.09 | — | — |
| Zhenjiang | — | — | 40.58 | 42.30 | 4.17 | — | 164.29 | 39.93 | 8.07 | 361.71 | 69.98 | — | — | — | — | — | — |
| Taizhou | 0.35 | 0.97 | 17.77 | 297.09 | 15.82 | — | 7.40 | 1.48 | 12.90 | 578.07 | 111.84 | — | — | — | — | — | — |
| Suqian | 5.92 | 7.77 | 146.14 | 260.75 | 29.67 | — | 923.53 | 224.48 | 26.05 | 1167.05 | 225.79 | — | — | — | 80.56 | — | — |
| Hangzhou | 1.23 | 0.74 | 15.45 | 333.26 | 23.12 | — | 959.79 | 102.66 | 17.97 | 804.96 | 155.74 | — | — | — | 86.57 | — | — |
| Ningbo | 0.71 | 0.80 | 9.56 | 165.95 | — | — | 537.08 | 57.45 | 10.54 | 472.28 | 91.38 | — | — | — | 62.00 | — | — |
| Wenzhou | 2.47 | 0.74 | 6.55 | 112.60 | 14.16 | — | 318.72 | 34.09 | 8.65 | 387.40 | 74.95 | — | — | — | 131.64 | — | — |
| Jiaxing | — | — | 6.65 | 374.83 | — | 58.91 | 429.45 | 45.93 | 22.84 | 1023.31 | 197.99 | — | — | — | — | — | — |
| Huzhou | 0.26 | — | 8.34 | 131.62 | 35.22 | — | 421.54 | 45.09 | 27.78 | 1244.38 | 240.76 | — | — | — | 61.35 | — | — |
| Shaoxing | 0.93 | 0.11 | 12.13 | 193.84 | 11.06 | — | 306.56 | 32.79 | 10.05 | 450.24 | 87.11 | — | — | — | 50.23 | — | — |

Continued Table S1

| | Beef | Cow | Sow | Hog | Goat | Sheep | Layer | Laying duck | Broiler | Meat duck | Goose | Horse | Donkey | Mule | Rabbit | Cattle | Buffalo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jinhua | 2.46 | 1.96 | 11.96 | 265.22 | 8.27 | — | 373.58 | 39.96 | 10.31 | 461.69 | 89.33 | — | — | — | 10.24 | — | — |
| Zhoushan | 0.03 | — | — | 22.32 | — | — | — | — | 0.93 | 41.66 | 8.06 | — | — | — | 6.10 | — | — |
| Taizhou | — | — | 5.80 | 92.15 | 6.40 | — | 244.76 | 26.18 | 10.94 | 489.99 | 94.80 | — | — | — | 58.17 | — | — |
| Lishui | — | — | 4.55 | 86.66 | 7.92 | — | 89.22 | 9.54 | 40.32 | 1806.19 | 349.45 | — | — | — | 11.85 | — | — |
| Quzhou | 1.36 | — | 17.23 | 400.45 | 4.53 | — | 163.31 | 17.47 | 13.13 | 588.25 | 113.81 | — | — | — | — | — | — |
| Hefei | 5.07 | 3.59 | 15.25 | 285.48 | 8.54 | 0.45 | 861.96 | 209.46 | 75.69 | 3390.88 | 656.05 | — | — | — | 3.76 | — | — |
| Huaibei | 3.05 | 0.84 | — | 68.23 | 100.15 | 0.65 | 580.11 | 140.97 | 8.17 | 365.95 | 70.80 | 0.004 | 0.06 | 0.002 | 21.37 | — | — |
| Anqing | 7.09 | — | 17.89 | 284.97 | 7.69 | — | 1631.00 | 444.51 | 29.94 | — | — | — | — | — | 2.00 | — | — |
| Boshou | 13.53 | — | — | 304.66 | 126.99 | — | 438.70 | 106.60 | 11.57 | 518.27 | 100.27 | 0.04 | 0.01 | 0.03 | — | — | — |
| Suzhou | 15.76 | — | — | 483.34 | 241.66 | 3.26 | 1657.91 | 402.88 | 23.10 | 1034.75 | 200.20 | 0.005 | 0.01 | 0.003 | — | — | — |
| Bengbu | 26.67 | — | — | 202.87 | 73.70 | 0.47 | 470.98 | 114.45 | 31.43 | 1408.07 | 272.43 | — | — | — | — | — | — |
| Fuyang | 31.60 | — | — | 560.37 | 138.92 | — | 909.21 | 220.94 | 26.42 | 1183.72 | 229.02 | 0.02 | 0.12 | 0.02 | — | — | — |
| Huainan | 5.05 | — | — | 50.67 | 13.06 | — | 427.94 | 103.99 | 11.30 | 506.30 | 97.96 | — | — | — | — | — | — |
| Chuzhou | 12.72 | — | — | 335.62 | 37.21 | 0.23 | 721.84 | 175.41 | 28.99 | 1298.97 | 251.32 | — | — | — | — | — | — |
| Liu'an | 11.37 | — | — | 405.70 | 46.48 | — | 774.29 | 188.16 | 56.55 | 2533.44 | 490.16 | — | — | — | — | — | — |
| Ma'anshan | 0.20 | — | — | 37.06 | 6.72 | — | 132.64 | 32.23 | 15.78 | 707.14 | 136.81 | — | — | — | — | — | — |
| Wuhu | 2.70 | — | — | 83.15 | 2.92 | — | 516.96 | 125.62 | 25.95 | 1162.41 | 224.90 | — | — | — | — | — | — |
| Xuancheng | 2.30 | — | — | 103.72 | 4.66 | — | 314.63 | 76.46 | 43.47 | 1947.60 | 376.81 | — | — | — | — | — | — |
| Tongling | 0.11 | — | — | 10.24 | — | — | 64.32 | 15.63 | — | — | — | — | — | — | — | — | — |
| Chizhou | 1.07 | — | — | 73.93 | 1.41 | — | 237.85 | 57.80 | 8.54 | 382.44 | 73.99 | — | — | — | — | — | — |
| Huangshan | 0.81 | — | — | 96.38 | 0.49 | 0.03 | 137.06 | 33.31 | 2.14 | 95.73 | 18.52 | 0.03 | 0.003 | 0.004 | — | — | — |

Table S2. The fertilizer consumption by type and prefectural city in the YRD region, and the provincial-level total consumption from statistics (metric tons).

| | Urea | ABC | AN | AS | DAP | NPK | Other | Total | Statistics |
|---|---|---|---|---|---|---|---|---|---|
| **Shanghai** | **38522.2** | **1819.4** | **44.4** | **6.2** | **2033.7** | **62064.8** | **42.4** | **104533.1** | **89000** |
| Nanjing | 55146.7 | 2871.5 | 91.3 | 12.7 | 2645.4 | 62403.7 | 87.1 | 123258.4 | |
| Wuxi | 52579.2 | 3148.5 | 101.4 | 14.1 | 2347.9 | 65723.9 | 96.8 | 124011.7 | |
| Xuzhou | 172364.1 | 10517.6 | 354.8 | 49.4 | 5962.7 | 158593.2 | 338.6 | 348180.3 | |
| Changzhou | 34264.2 | 2074.6 | 93.4 | 13.0 | 1245.9 | 31052.6 | 89.2 | 68832.9 | |
| Suzhou | 37217.3 | 2230.9 | 57.6 | 8.0 | 1687.8 | 48076.9 | 55.0 | 89333.4 | |
| Nantong | 148372.9 | 7212.5 | 256.6 | 35.8 | 6750.4 | 138864.2 | 245.0 | 301737.4 | |
| Lianyungang | 97247.4 | 5461.8 | 121.6 | 17.0 | 3958.0 | 100200.1 | 116.1 | 207121.9 | |
| Huai'an | 119622.4 | 6238.7 | 170.0 | 23.7 | 4602.1 | 112485.5 | 162.3 | 243304.7 | |
| Yancheng | 222512.3 | 9824.1 | 347.0 | 48.4 | 8286.0 | 236255.7 | 331.2 | 477604.6 | |
| Yangzhou | 74431.4 | 3258.3 | 99.9 | 13.9 | 2118.3 | 73909.4 | 95.4 | 153926.5 | |
| Zhenjiang | 48497.0 | 2494.6 | 83.8 | 11.7 | 1828.2 | 40582.9 | 80.0 | 93578.1 | |
| Taizhou | 114868.5 | 5766.9 | 185.9 | 25.9 | 4691.2 | 106345.4 | 177.5 | 232061.3 | |
| Suqian | 112064.1 | 6159.3 | 162.5 | 22.6 | 3864.9 | 108296.8 | 155.1 | 230725.2 | |
| **Jiangsu total** | **1289187.3** | **67259.1** | **2125.7** | **296.2** | **49988.8** | **1282790.1** | **2029.1** | **2693676.3** | **2609000** |
| Hangzhou | 33929.4 | 3299.9 | 30.1 | 4.2 | 547.9 | 58816.2 | 28.7 | 96656.4 | |
| Ningbo | 32399.1 | 3521.5 | 35.6 | 5.0 | 831.4 | 56213.0 | 34.0 | 93039.5 | |
| Wenzhou | 21741.3 | 3051.4 | 1.2 | 0.2 | 169.6 | 33691.6 | 1.1 | 58656.3 | |
| Jiaxing | 37957.0 | 4132.5 | 35.5 | 5.0 | 803.5 | 57789.3 | 33.9 | 100756.7 | |
| Huzhou | 28860.3 | 3742.5 | 26.0 | 3.6 | 576.3 | 35435.9 | 24.8 | 68669.4 | |
| Shaoxing | 33122.2 | 3801.7 | 35.2 | 4.9 | 768.2 | 46923.1 | 33.6 | 84688.9 | |
| Jinhua | 28634.6 | 3062.7 | 30.3 | 4.2 | 689.9 | 39802.2 | 28.9 | 72252.8 | |
| Zhoushan | 2736.0 | 238.6 | 4.1 | 0.6 | 84.7 | 5136.9 | 4.0 | 8204.9 | |
| Taizhou | 27127.9 | 2912.9 | 31.8 | 4.4 | 500.1 | 46903.3 | 30.4 | 77510.8 | |
| Lishui | 20953.3 | 2403.5 | 36.6 | 5.1 | 563.7 | 32309.7 | 34.9 | 56306.8 | |
| Quzhou | 27943.3 | 3597.7 | 21.1 | 2.9 | 461.3 | 33127.1 | 20.2 | 65173.5 | |
| **Zhejiang total** | **295404.4** | **33764.7** | **287.6** | **40.1** | **5996.5** | **446148.3** | **274.5** | **781916.0** | **717000** |
| Hefei | 89980.7 | 3144.9 | 32.4 | 4.5 | 4567.2 | 115602.5 | 31.0 | 213363.1 | |
| Huaibei | 26884.4 | 678.8 | 12.2 | 1.7 | 897.6 | 42907.1 | 11.7 | 71393.5 | |

Continued Table S2

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Anqing | 104403.0 | 2946.8 | 34.1 | 4.7 | 5869.2 | 120970.4 | 32.5 | 234260.7 | |
| Bozhou | 112979.8 | 2989.4 | 68.5 | 9.6 | 5221.0 | 182035.0 | 65.4 | 303368.7 | |
| Suzhou | 104919.7 | 2576.0 | 35.6 | 5.0 | 3810.2 | 151179.4 | 34.0 | 262559.9 | |
| Bengbu | 72865.7 | 1953.0 | 36.4 | 5.1 | 4875.7 | 119840.0 | 34.8 | 199610.6 | |
| Fuyang | 139596.0 | 3727.8 | 75.8 | 10.6 | 5704.0 | 223240.0 | 72.4 | 372426.6 | |
| Huainan | 29430.1 | 845.1 | 14.8 | 2.1 | 1092.6 | 48097.9 | 14.2 | 79496.8 | |
| Chuzhou | 115575.2 | 2824.0 | 53.9 | 7.5 | 5953.7 | 176377.9 | 51.5 | 300843.7 | |
| Liuan | 112162.7 | 2719.9 | 36.0 | 5.0 | 3482.5 | 155355.5 | 34.4 | 273796.0 | |
| Maanshan | 28821.6 | 721.0 | 10.6 | 1.5 | 1237.6 | 39867.0 | 10.1 | 70669.3 | |
| Wuhu | 46288.4 | 1159.8 | 17.4 | 2.4 | 2845.1 | 61312.2 | 16.6 | 111641.8 | |
| Xuancheng | 41839.9 | 1015.9 | 15.7 | 2.2 | 1652.2 | 56933.7 | 15.0 | 101474.6 | |
| Tongling | 5782.1 | 141.1 | 1.9 | 0.3 | 319.6 | 7754.7 | 1.8 | 14001.5 | |
| Chizhou | 26140.2 | 559.0 | 4.6 | 0.6 | 1588.7 | 29744.6 | 4.4 | 58042.0 | |
| Huangshan | 15024.7 | 364.5 | 8.3 | 1.2 | 594.2 | 19994.1 | 7.9 | 35994.8 | |
| **Anhui total** | **1072694.0** | **28366.9** | **458.3** | **63.9** | **49711.1** | **1551211.9** | **437.5** | **2702943.6** | **2731025** |
| **`YRD total** | **2695807.8** | **131210.1** | **2916.1** | **406.4** | **107730.2** | **3342215.0** | **2783.4** | **6283069.0** | **6146025** |

Note: ABC, AN, AS, DAP, and NPK represent ammonium bicarbonate, ammonium nitrate, ammonium sulfate, diammonium phosphate and complex-fertilizer, respectively.

Table S3. The NH$_3$ emission factors used in E1.

| Source | EFs | Unit | Reference | Source | EFs | Unit | Reference |
|---|---|---|---|---|---|---|---|
| **Fertilizer Application** | | | | waste incineration | 0.21 | kg/t | Zheng et al. (2012) |
| urea | 17.4 | NH$_3$-N/% | | waste compost | 1.275 | kg/t | Zhou et al. (2015) |
| ammonium bicarbonate | 21.3 | NH$_3$-N/% | Cai et al. (2002); | sewage treatment | 0.28 | g/m$^3$ | Kang et al. (2016) |
| ammonium sulfate | 2 | NH$_3$-N/% | Dong et al.(2009); Huo et al. (2015) | **Transportation** | | | |
| ammonium nitrate | 8 | NH$_3$-N/% | Su et al. (2006) | light duty gasoline vehicle | 43.1 | mg/km | Huang et al. (2012) |
| others | 4 | NH$_3$-N/% | | light duty diesel vehicle | 4.1 | mg/km | Zheng et al. (2012) |
| diammoniumphosphate | 7.3 | NH$_3$-N/% | Zhou et al. (2015) | heavy duty gasoline vehicle | 28 | mg/km | Zhou et al. (2015) |
| NPK Compound-Fertilizer | 5 | NH$_3$-N/% | Zhou et al. (2015) | heavy duty diesel vehicle | 16.9 | mg/km | Kang et al. (2016) |
| **Livestock** | | | | motorcycle | 7 | mg/km | Yin et al. (2010) |
| beef cattle | 19.8 | kg/a | Zheng et al. (2012) | **Fuel Combustion** | | | |
| dairy cow | 30.53 | kg/a | Zhou et al. (2015) | industrial coal combustion | 0.02 | kg/t | Huang et al. (2012) |
| sow | 14.53 | kg/a | Yin et al. (2010) | industrial oil combustion | 0.1 | kg/m$^3$ | Zheng et al. (2012) |
| hog | 2.87 | kg/a | Dong et al. (2010) | industrial gas combustion | 51.3 | kg/10$^6$m$^3$ | Zhou et al. (2015) |
| goat | 5.27 | kg/a | Pan et al. (2015) | domestic coal combustion | 0.9 | kg/t | Kang et al. (2016) |
| sheep | 5.23 | kg/a | Shen et al. (2014) | domestic oil combustion | 0.12 | kg/m$^3$ | Yin et al. (2010) |
| layer | 0.46 | kg/a | Liu et al. (2015) | domestic gas combustion | 320.51 | kg/10$^6$m$^3$ | |
| laying duck | 0.35 | kg/a | Yang et al. (2008) | **Industry Sources** | | | |
| broiler | 0.14 | kg/a | | ammonium synthesis | 1 | kg/t | Huang et al. (2012) |
| duck | 0.03 | kg/a | | nitrogenous fertilizer | 5 | kg/t | Zheng et al. (2012) |
| goose | 0.23 | kg/a | | phosphate fertilizer | 0.07 | kg/t | Zhou et al. (2015) |
| horse | 17.26 | kg/a | | coking | 0.07 | kg/t | Kang et al. (2016) |
| donkey | 17.26 | kg/a | | **Human Being** | | | |
| mule | 17.26 | kg/a | | human breath | 3.64 | g/(cap·yr) | Yin et al. (2010) |

Table S4. The relevant parameters used for correction of emission factors of fertilizer activity in E2.

| Fertilizer Categories | pH | | T | | $CF_{rate}$ | $CF_{method}$ |
|---|---|---|---|---|---|---|
| | pH slope | pH intercept | $T_{basal}$ | T slope | | |
| Urea | 6.265 | -25.029 | 27.6 | 0.35 | 1.18 | 0.32 |
| ABC | 6.147 | -14.994 | 27.6 | 0.44 | 1.18 | 0.32 |
| AN | 1.793 | -10.45 | 13 | 0.06 | 1.18 | 0.32 |
| AS | 0 | 0.8 | 0 | 0.01 | 1.18 | 0.32 |
| Other nitrogen fertilizers | 0 | 0.8 | 0 | 0.01 | 1.18 | 0.32 |
| DAP | 0 | 0.8 | 0 | 0.01 | 1.18 | 0.32 |
| NPK | 2.806 | -10.158 | 13 | 0.01 | 1.18 | 0.32 |

Table S5. The arameters used in estimates of annual TAN excretion per cattle.

| | Raising cycle | Excretion (kg/cattle/day) | | Nitrogen content (%) | | TAN (%) | Annual TAN (tons/cattle) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Urine | Excrement | Urine | Excrement | | Urine | Excrement | Total |
| Beef | 365 | 7.5 | 13.5 | 0.9 | 0.38 | 60 | 0.0148 | 0.0112 | 0.0260 |
| Cow | 365 | 12 | 23.5 | 0.9 | 0.38 | 60 | 0.0237 | 0.0196 | 0.0432 |
| Horse | 365 | 6.5 | 15 | 1.4 | 0.2 | 60 | 0.0199 | 0.0066 | 0.0265 |
| Donkey | 365 | 6.5 | 15 | 1.4 | 0.2 | 60 | 0.0199 | 0.0066 | 0.0265 |
| Mule | 365 | 6.5 | 15 | 1.4 | 0.2 | 60 | 0.0199 | 0.0066 | 0.0265 |
| Sow | 365 | 5.7 | 2.1 | 0.4 | 0.34 | 70 | 0.0058 | 0.0018 | 0.0076 |
| Hog | 75 | 3.2 | 1.5 | 0.4 | 0.34 | 70 | 0.0007 | 0.0003 | 0.0009 |
| Goat | 365 | 0.705 | 2.05 | 1.35 | 0.75 | 55 | 0.0019 | 0.0031 | 0.0050 |
| Sheep | 365 | 0.705 | 2.05 | 1.35 | 0.75 | 55 | 0.0019 | 0.0031 | 0.0050 |
| Layer | 365 | — | 0.12 | — | 1.63 | 70 | — | 0.0005 | 0.0005 |
| Laying duck | 365 | — | 0.13 | — | 1.1 | 70 | — | 0.0004 | 0.0004 |
| Broiler | 50 | — | 0.09 | — | 1.63 | 70 | — | $5\times10^{-5}$ | $5\times10^{-5}$ |
| Meat duck | 55 | — | 0.1 | — | 1.1 | 70 | — | $4\times10^{-5}$ | $4\times10^{-5}$ |
| Goose | 70 | — | 0.1 | — | 0.55 | 70 | — | $3\times10^{-5}$ | $3\times10^{-5}$ |
| Rabbit | 55 | 0.3 | 0.15 | 0.15 | 1.72 | 45 | — | $6\times10^{-5}$ | $7\times10^{-5}$ |
| Cattle | 365 | 10 | 18 | 0.9 | 0.6 | 50 | 0.0164 | 0.01971 | 0.0361 |
| Buffalo | 365 | 10 | 18 | 0.9 | 0.6 | 45 | 0.0148 | 0.0177 | 0.0325 |

Table S6. The temperature-dependant emission factors by stage/phase in livestock farming in E2 (% TAN).

| | $EF_{outdoors}$ | $EF_{Housing}$ (liquid) | | | $EF_{Housing}$ (solid) | | | $EF_{Storage}$ (liquid) | | | | $EF_{Storage}$ (solid) | | | | $EF_{spreading}$ (liquid) | $EF_{spreading}$ (solid) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $<10\,^{\circ}C$ | $10\text{-}20\,^{\circ}C$ | $>20\,^{\circ}C$ | $<10\,^{\circ}C$ | $10\text{-}20\,^{\circ}C$ | $>20\,^{\circ}C$ | $NH_3$ | $N_2O$ | $NO$ | $N_2$ | $NH_3$ | $N_2O$ | $NO$ | $N_2$ | | |
| Free-range | | | | | | | | | | | | | | | | | |
| Beef | 53 | 7 | 10.5 | 14 | 7 | 10.5 | 14 | 20 | 1 | 0 | 0.3 | 27 | 8 | 1 | 30 | 55 | 79 |
| Cow | 41.5 | 7 | 10.5 | 14 | 7 | 10.5 | 14 | 20 | 1 | 0 | 0.3 | 27 | 8 | 1 | 30 | 55 | 79 |
| Horse | 0 | 9.3 | 14 | 18.7 | 9.3 | 14 | 18.7 | 35 | 0 | 0 | 0.3 | 35 | 8 | 1 | 30 | 90 | 81 |
| Donkey | 0 | 9.3 | 14 | 18.7 | 9.3 | 14 | 18.7 | 35 | 0 | 0 | 0.3 | 35 | 8 | 1 | 30 | 90 | 81 |
| Mule | 0 | 9.3 | 14 | 18.7 | 9.3 | 14 | 18.7 | 35 | 0 | 0 | 0.3 | 35 | 8 | 1 | 30 | 90 | 81 |
| Sow | 0 | 9.2 | 14.7 | 20.2 | 9.2 | 14.7 | 20.2 | 14 | 0 | 0 | 0.3 | 45 | 5 | 1 | 30 | 40 | 81 |
| Hog | 0 | 6.2 | 10.2 | 14.2 | 6.2 | 10.2 | 14.2 | 14 | 0 | 0 | 0.3 | 45 | 5 | 1 | 30 | 40 | 81 |
| Goat | 64 | 7 | 10.5 | 14 | 7 | 10.5 | 14 | 24 | 4 | 0 | 0.3 | 27.5 | 7.5 | 1 | 30 | 72.5 | 80 |
| Sheep | 64 | 7 | 10.5 | 14 | 7 | 10.5 | 14 | 24 | 4 | 0 | 0.3 | 27.5 | 7.5 | 1 | 30 | 72.5 | 80 |
| Layer | 69 | 24.9 | 45.2 | 56.5 | 24.9 | 45.2 | 56.5 | 0 | 0 | 0 | 0 | 14 | 4 | 1 | 30 | 0 | 63 |
| Laying duck | 54 | 24.9 | 45.2 | 56.5 | 24.9 | 45.2 | 56.5 | 0 | 0 | 0 | 0 | 24 | 3 | 1 | 30 | 0 | 63 |
| Broiler | 66 | 22.2 | 40.3 | 50.4 | 22.2 | 40.3 | 50.4 | 0 | 0 | 0 | 0 | 17 | 3 | 1 | 30 | 0 | 63 |
| Meat duck | 54 | 22.2 | 40.3 | 50.4 | 22.2 | 40.3 | 50.4 | 0 | 0 | 0 | 0 | 24 | 3 | 1 | 30 | 0 | 63 |
| Goose | 54 | 22.2 | 40.3 | 50.4 | 22.2 | 40.3 | 50.4 | 0 | 0 | 0 | 0 | 24 | 3 | 1 | 30 | 0 | 63 |
| Intensive | | | | | | | | | | | | | | | | | |
| Beef | 53 | 7 | 10.5 | 14 | 7 | 10.5 | 14 | 16 | 1 | 0 | 0.3 | 4.2 | 8 | 1 | 30 | 55 | 79 |
| Cow | 41.5 | 7 | 10.5 | 14 | 7 | 10.5 | 14 | 16 | 1 | 0 | 0.3 | 4.2 | 8 | 1 | 30 | 55 | 79 |
| Horse | 0 | 9.3 | 14 | 18.7 | 9.3 | 14 | 18.7 | 16 | 0 | 0 | 0.3 | 4.2 | 8 | 1 | 30 | 90 | 81 |
| Donkey | 0 | 9.3 | 14 | 18.7 | 9.3 | 14 | 18.7 | 16 | 0 | 0 | 0.3 | 4.2 | 8 | 1 | 30 | 90 | 81 |
| Mule | 0 | 9.3 | 14 | 18.7 | 9.3 | 14 | 18.7 | 16 | 0 | 0 | 0.3 | 4.2 | 8 | 1 | 30 | 90 | 81 |

Continued Table S6

| | $EF_{outdoors}$ | $EF_{Housing}$ (liquid) | | | $EF_{Housing}$ (solid) | | | $EF_{Storage}$ (liquid) | | | | $EF_{Storage}$ (solid) | | | | $EF_{spreading}$ (liquid) | $EF_{spreading}$ (solid) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $<10\,^{o}C$ | $10\text{-}20\,^{o}C$ | $>20\,^{o}C$ | $<10\,^{o}C$ | $10\text{-}20\,^{o}C$ | $>20\,^{o}C$ | $NH_3$ | $N_2O$ | NO | $N_2$ | $NH_3$ | $N_2O$ | NO | $N_2$ | | |
| | | | | | | | Intensive | | | | | | | | | | |
| Sow | 0 | 8.9 | 14.3 | 19.7 | 8.9 | 14.3 | 19.7 | 3.8 | 0 | 0 | 0.3 | 4.6 | 5 | 1 | 30 | 40 | 81 |
| Hog | 0 | 11.3 | 18.5 | 25.7 | 11.3 | 18.5 | 25.7 | 3.8 | 0 | 0 | 0.3 | 4.6 | 5 | 1 | 30 | 40 | 81 |
| Goat | 64 | 7 | 10.5 | 14 | 7 | 10.5 | 14 | 16 | 4 | 0 | 0.3 | 4.2 | 7.5 | 1 | 30 | 72.5 | 80 |
| Sheep | 64 | 7 | 10.5 | 14 | 7 | 10.5 | 14 | 16 | 4 | 0 | 0.3 | 4.2 | 7.5 | 1 | 30 | 72.5 | 80 |
| Layer | 69 | 0 | 0 | 0 | 19.7 | 35.9 | 44.9 | 0 | 0 | 0 | 0 | 3.7 | 4 | 1 | 30 | 0 | 63 |
| Laying duck | 54 | 0 | 0 | 0 | 19.7 | 35.9 | 44.9 | 0 | 0 | 0 | 0 | 3.7 | 3 | 1 | 30 | 0 | 63 |
| Broiler | 66 | 0 | 0 | 0 | 22.2 | 40.3 | 50.4 | 0 | 0 | 0 | 0 | 0.8 | 3 | 1 | 30 | 0 | 63 |
| Meat duck | 54 | 0 | 0 | 0 | 22.2 | 40.3 | 50.4 | 0 | 0 | 0 | 0 | 0.8 | 3 | 1 | 30 | 0 | 63 |
| Goose | 54 | 0 | 0 | 0 | 22.2 | 40.3 | 50.4 | 0 | 0 | 0 | 0 | 0.8 | 3 | 1 | 30 | 0 | 63 |

Table S7. Model performance for meteorological parameters in D2.

| Parameters | Indicator | January | April | July | October | Benchmark |
|---|---|---|---|---|---|---|
| Wind speed | Mean OBS (m/s) | 2.50 | 2.62 | 2.52 | 2.64 | |
| | Mean SIM (m/s) | 2.55 | 2.52 | 2.38 | 2.63 | |
| | Bias (m/s) | 0.05 | -0.10 | -0.14 | -0.009 | $\leq\pm0.5$ |
| | RMSE (m/s) | 0.27 | 0.29 | 0.33 | 0.27 | $\leq2.0$ |
| | IOA | 0.95 | 0.94 | 0.94 | 0.97 | $\geq0.6$ |
| | $R^2$ | 0.82 | 0.82 | 0.82 | 0.89 | |
| | NMB (%) | 1.91 | -3.94 | -5.53 | -0.32 | |
| | NME (%) | 8.37 | 9.10 | 10.53 | 7.75 | |
| Wind direction | Mean OBS (°) | 184.29 | 163.29 | 169.28 | 174.34 | |
| | Mean SIM (°) | 165.37 | 147.09 | 159.80 | 155.66 | |
| | Bias (°) | -18.91 | -15.68 | -9.17 | -18.68 | $\leq\pm10$ |
| | RMSE (°) | 33.88 | 27.82 | 23.15 | 30.93 | |
| | IOA | 0.87 | 0.88 | 0.87 | 0.92 | |
| | $R^2$ | 0.69 | 0.74 | 0.63 | 0.81 | |
| | NMB (%) | -10.26 | -9.92 | -5.60 | -10.72 | |
| | NME (%) | 13.95 | 13.41 | 9.62 | 13.91 | |
| Temperature | Mean OBS (°C) | 5.60 | 16.30 | 27.33 | 18.69 | |
| | Mean SIM (°C) | 7.09 | 16.03 | 26.64 | 18.75 | |
| | Bias (°C) | 1.49 | -0.26 | -0.66 | 0.06 | $\leq0.5$ |
| | RMSE (°C) | 1.76 | 0.95 | 1.27 | 0.69 | |
| | IOA | 0.95 | 0.98 | 0.95 | 0.99 | $\geq0.7$ |
| | $R^2$ | 0.95 | 0.94 | 0.89 | 0.96 | |
| | NMB (%) | 26.60 | -1.62 | -2.51 | 0.34 | |
| | NME (%) | 28.00 | 4.70 | 3.57 | 2.94 | |
| Relative humidity | Mean OBS (%) | 65.16 | 75.69 | 79.81 | 71.96 | |
| | Mean SIM (%) | 61.87 | 76.21 | 82.24 | 70.80 | |
| | Bias (%) | -3.29 | 0.51 | 2.36 | -1.16 | |
| | RMSE (%) | 6.61 | 3.86 | 4.24 | 4.07 | |
| | IOA | 0.97 | 0.98 | 0.95 | 0.98 | $\geq0.7$ |
| | $R^2$ | 0.92 | 0.95 | 0.89 | 0.94 | |
| | NMB (%) | -5.06 | 0.69 | 3.05 | -1.61 | |
| | NME (%) | 8.42 | 4.23 | 4.29 | 4.15 | |

Note: OBS and SIM indicate the results from observation and simulation, respectively. The Bias, IOA, RMSE, NMB and NME were calculated using following equations (P and O indicates the results from modeling prediction and observation, respectively):
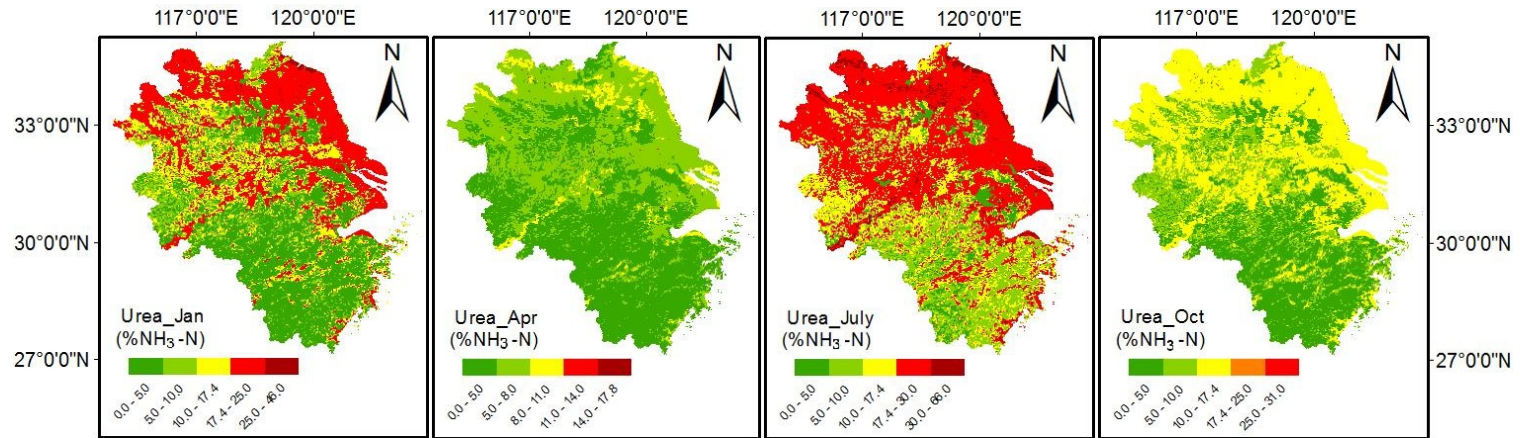
$$Bias = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i); \quad IOA = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}\left(\left|P_i - \overline{O}\right| + \left|O_i - \overline{O}\right|\right)^2}; \quad RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2}$$

$$NMB = \frac{\sum_{i=1}^{n}(P_i - O_i)}{\sum_{i=1}^{n}O_i} \times 100\%; \quad NME = \frac{\sum_{i=1}^{n}\left|P_i - O_i\right|}{\sum_{i=1}^{n}O_i} \times 100\%$$
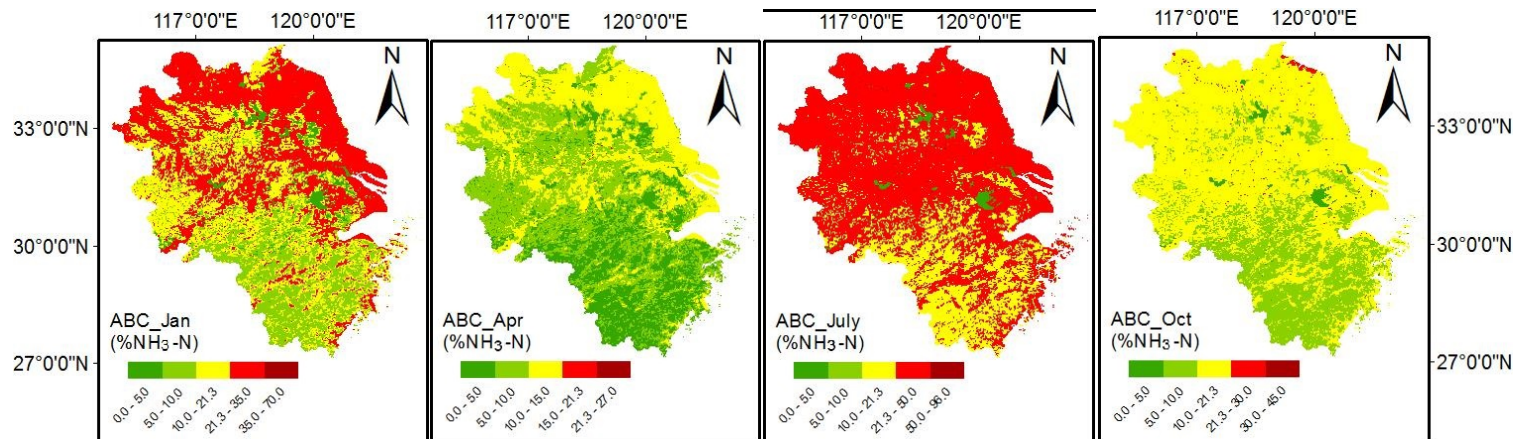
Table S8. The inter-annual change in $SO_2$ and $NO_2$ VCDs for the YRD region 2012-2014 (%)

|         | Jiangsu | Zhejiang | Anhui  | Shanghai | Total YRD |
|---------|---------|----------|--------|----------|-----------|
| $SO_2$  | -49.94  | -29.53   | -51.38 | -56.72   | -47.84    |
| $NO_2$  | -29.12  | -26.22   | -35.69 | -29.48   | -30.91    |

Figure S1.The NH$_3$ volatilization of urea and ABC application in E2



(a) NH$_3$ volatility of urea



(b) NH$_3$ volatility of ABC

Figure S2. Total ammoniacal nitrogen (TAN) for three main raising systems (taken from Huang et al., 2012)
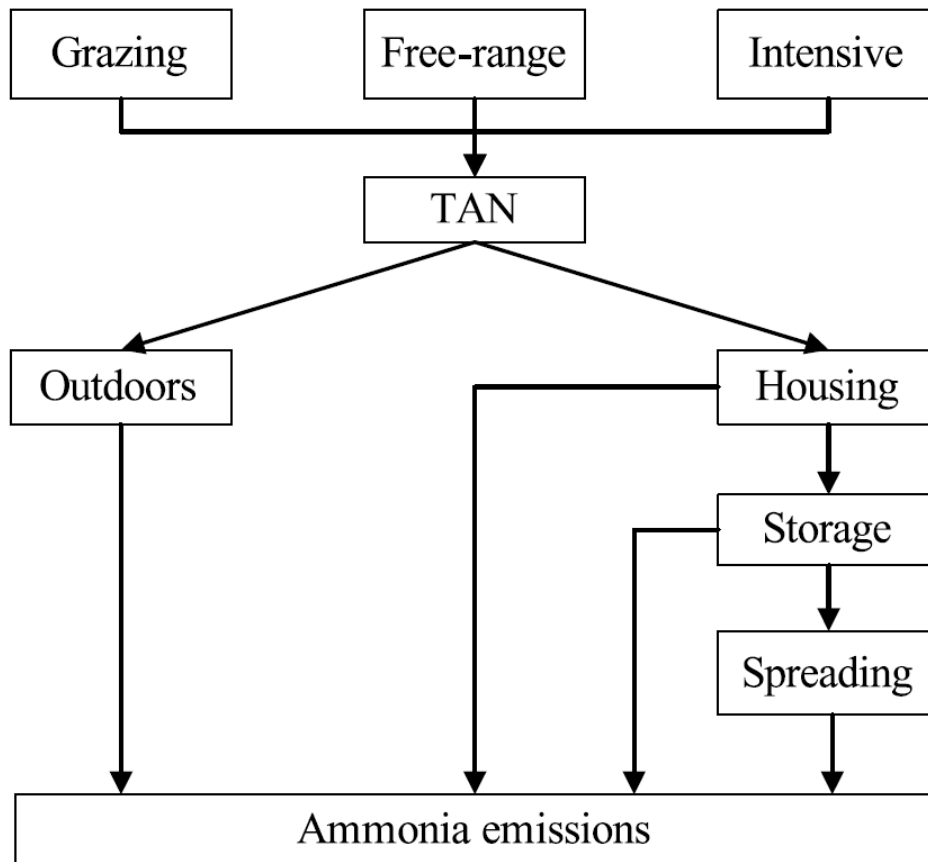
Figure S3. The daily NH$_3$ concentration at JSPAES for October 2014 from observation and simulation with E1 and E2.
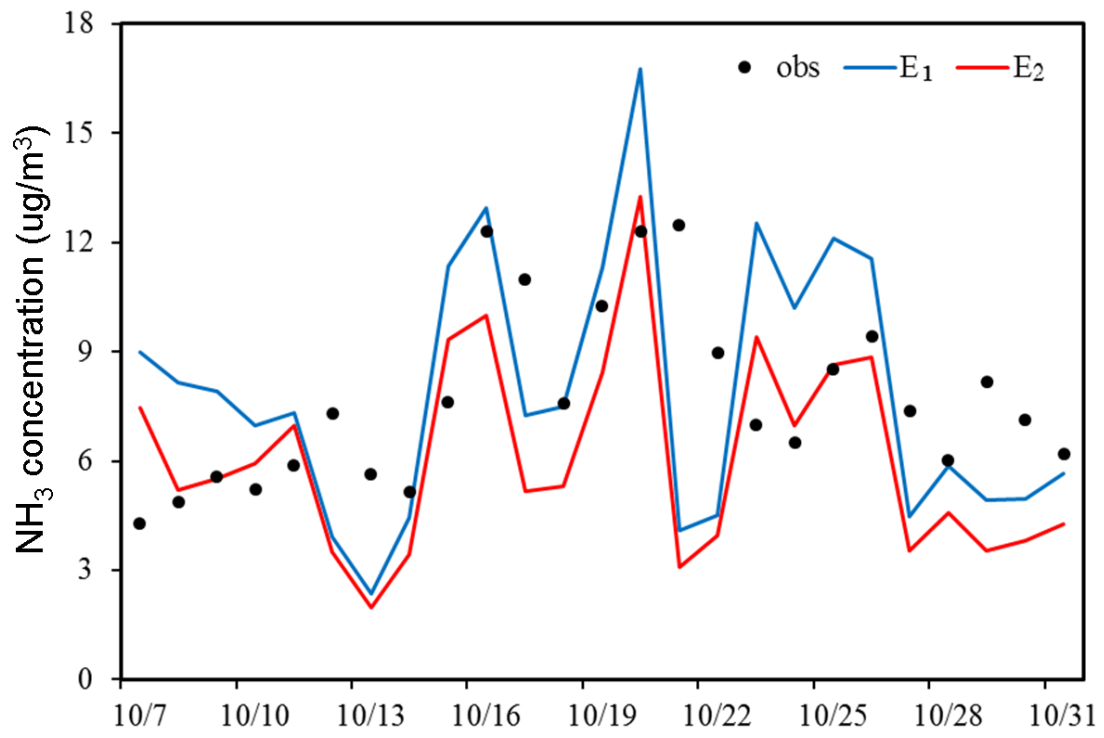
Figure S4. The NH$_3$ volatilization rates under different soil pH values for urea (a) and ABC fertilizer (b). The blue dots indicate the values by grid in the YRD region in E2, while the red dots indicate the results from the field measurements by Zhong et al. (2006) (a) and Zhang et al. (2002) (b). The solid lines and equations were obtained from linear regression for the gridded values in the YRD region in E2.



NH3-N/%

NH3-N/% = 5.8pH- 26.0
R² = 0.9975

pH

(a) Urea



NH3-N/%

NH3-N/% = 5.7pH- 18.0
R² = 0.9922

pH
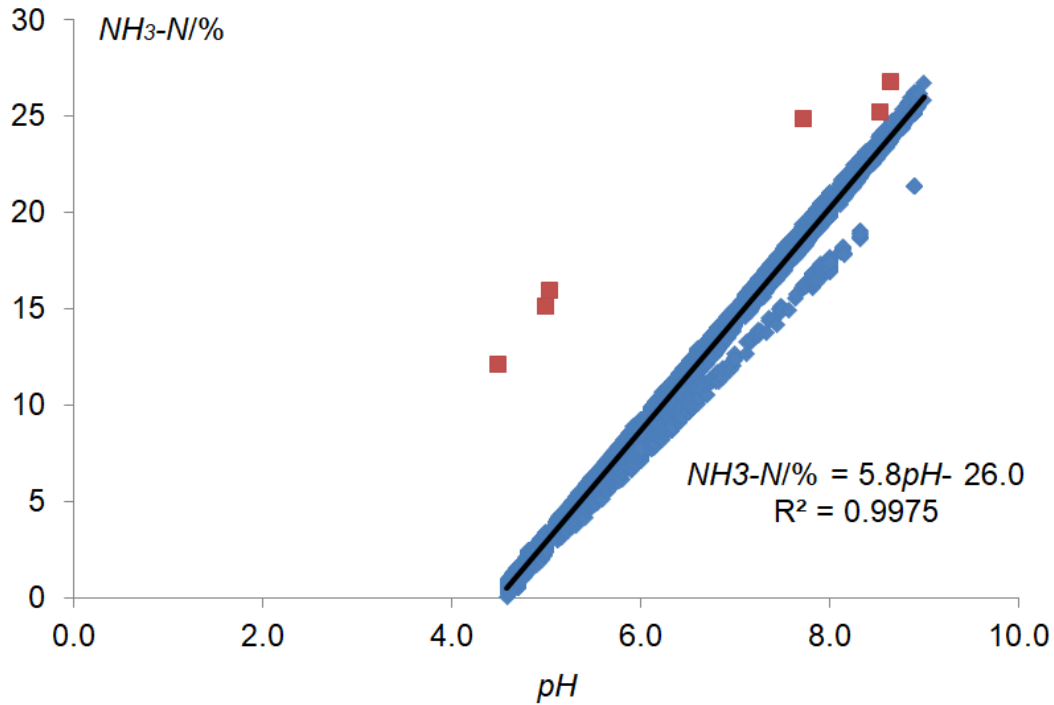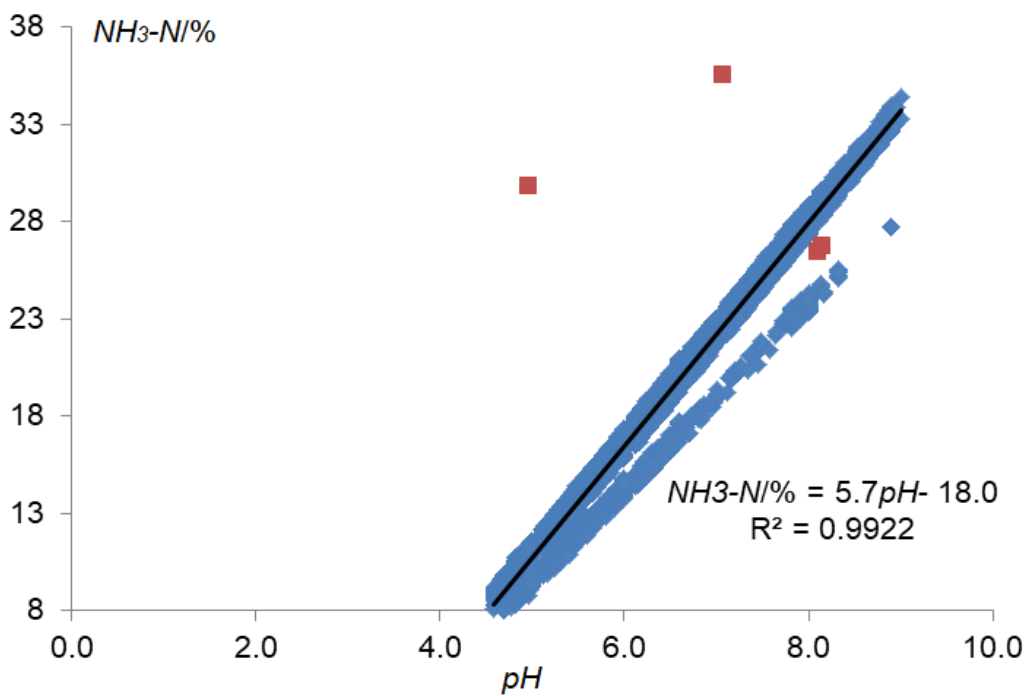
**(b)** ABC

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