Supplemental Material

Table S1 Average annual emissions of air pollutants (1999-2013) and chemicals (2001-2014)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Pollutants | **National total** | **National average** | **Ulsan** | **Sihwa/Banwol** | **Chungju/Daesan** | **Gwangyang Bay area** | **Pohang** |
| Nam-gu | Ulju-gun | Ansan-si | Siheung-si | Chungju-si | Seosan-si | Yeosu-si | Gwangyang-si | Pohang-si |
| CO [×107 ton (%)] | 72.98 | 0.32 |  1.51 (2.1)  |  1.03 (1.4)  |  0.43 (0.6)  |  0.44 (0.6)  |  0.53 (0.7)  |  0.49 (0.7)  |  1.05 (1.4)  |  0.50 (0.7)  |  0.58 (0.8)  |
| NOx [×107 ton (%)] | 111.12 | 0.49 |  3.69 (3.3)  |  1.71 (1.5)  |  0.67 (0.6)  |  0.81 (0.7)  |  0.40 (0.4)  |  1.08 (1.0)  |  2.91 (2.6)  |  2.50 (2.3)  |  1.54 (1.4)  |
| SOx [×107 ton (%)] | 44.63 | 0.19 |  3.57 (8.0)  |  2.29 (5.1)  |  0.24 (0.5)  |  0.27 (0.6)  |  0.07 (0.2)  |  1.10 (2.5)  |  3.22 (7.2)  |  2.38 (5.3)  |  1.14 (2.6)  |
| TSP [×107 ton (%)] | 15.7 | 0.07 |  0.43 (2.7)  |  0.69 (4.4)  |  0.04 (0.2)  |  0.05 (0.3)  |  0.04 (0.2)  |  0.04 (0.3)  |  0.30 (1.9)  |  0.93 (5.9)  |  0.56 (3.6)  |
| PM10 [×107 ton (%)] | 10.47 | 0.05 |  0.27 (2.5)  |  0.45 (4.3)  |  0.03 (0.3)  |  0.04 (0.4)  |  0.03 (0.3)  |  0.03 (0.3)  |  0.19 (1.8)  |  0.57 (5.4)  |  0.34 (3.3)  |
| PM2.5 [×107 ton (%)] | 7.47 | 0.03 |  0.13 (1.7)  |  0.09 (1.2)  |  0.01 (0.2)  |  0.04 (0.5)  |  0.01 (0.2)  |  0.03 (0.5)  |  0.15 (2.1)  |  0.70 (9.4)  |  0.56 (7.4)  |
| VOC [×107 ton (%)] | 73.96 | 0.32 |  3.92 (5.3)  |  1.74 (2.4)  |  0.84 (1.1)  |  0.92 (1.2)  |  0.32 (0.4)  |  2.05 (2.8)  |  3.34 (4.5)  |  0.81 (1.1)  |  0.68 (0.9)  |
| NH3 [×107 ton (%)] | 22.77 | 0.1 |  0.97 (4.3)  |  0.58 (2.5)  |  0.04 (0.2)  |  0.04 (0.2)  |  0.05 (0.2)  |  0.51 (2.3)  |  0.99 (4.4)  |  0.11 (0.5)  |  0.10 (0.4)  |
| Formaldehyde [kg, (%)] | 43,858 | 1,044 | 3,558 (8.1) | 534 (1.2) | 8,399 (19.2) | 1,077 (2.5) | 569 (1.3) | -  (  -  ) | 1,042 (2.4) | 815 (1.9) | 60 (0.1) |
| Benzene [kg, (%)] | 233,675 | 8,655 | 73,645 (31.5) | 41,265 (17.7) | 147 (0.1) | 773 (0.3) | 5 (0.0) | 4,453 (1.9) | 77,812 (33.3) | 17,661 (7.6) | 2,666 (1.1) |
| Vinyl chloride [kg, (%)] | 217,780 | 14,519 | 119,827 (55.0) | -  (  -  ) | 815 (0.4) | 0 (0.0) | -  (  -  ) | 1,571 (0.7) | 56,477 (25.9) | 38,679 (17.8) | -  (  -  ) |
| Acetaldehyde [kg, (%)] | 3,239 | 540 | 2,782 (85.9) | -  (  -  ) | -  (  -  ) | 19 (0.6) | -  (  -  ) | -  (  -  ) | 23 (0.7) | 23 (0.7) | -  (  -  ) |
| Ethylene oxide [kg, (%)] | 21,957 | 1,568 | 11,923 (54.3) | 128 (0.6) | 106 (0.5) | -  (  -  ) | -  (  -  ) | 400 (1.8) | 2,962 (13.5) | 5,503 (25.1) | -  (  -  ) |
| Trichloroethylene [kg, (%)] | 446,383 | 13,527 | 808 (0.2) | 704 (0.2) | 34,659 (7.8) | 27,025 (6.1) | 2,221 (0.5) | -  (  -  ) | 10 (0.0) | 1,057 (0.2) | 763 (0.2) |
| o-Toluidine [kg, (%)] | 6 | 6 | -  (  -  ) | -  (  -  ) | 6 (100.0) | -  (  -  ) | -  (  -  ) | -  (  -  ) | -  (  -  ) | -  (  -  ) | -  (  -  ) |
| Ethylbenzene [kg, (%)] | 816,484 | 25,515 | 475,273 (58.2) | 29,075 (3.6) | 491 (0.1) | 132 (0.0) | -  (  -  ) | 3,289 (0.4) | 8,680 (1.1) | 4,692 (0.6) | 381 (0.0) |
| Styrene [kg, (%)] | 204,967 | 5,256 | 95,656 (46.7) | 880 (0.4) | 1,693 (0.8) | 1,117 (0.5) | 15 (0.0) | 10,139 (4.9) | 50,708 (24.7) | 13,517 (6.6) | 1 (0.0) |
| Xylene [kg, (%)] | 8,866,247 | 132,332 | 3,840,306 (43.3) | 173,812 (2.0) | 14,833 (0.2) | 66,102 (0.7) | 5,947 (0.1) | 62,024 (0.7) | 49,488 (0.6) | 6,591 (0.1) | 33,445 (0.4) |
| Naphthalene [kg, (%)] | 12,042 | 860 | 127 (1.1) | 1,370 (11.4) | 4 (0.0) | -  (  -  ) | -  (  -  ) | 47 (0.4) | 353 (2.9) | 34 (0.3) | 1,416 (11.8) |
| 1,3-butadiene [kg, (%)] | 79,120 | 6,593 | 28,990 (36.6) | 1,376 (1.7) | 202 (0.3) | -  (  -  ) | 189 (0.2) | 3,148 (4.0) | 27,523 (34.8) | 12,992 (16.4) | -  (  -  ) |
| Phenol [kg, (%)] | 46,941 | 1,381 | 298 (0.6) | 4,596 (9.8) | 1,920 (4.1) | 69 (0.1) | 681 (1.5) | 0 (0.0) | 17,470 (37.2) | 937 (2.0) | 8,022 (17.1) |
| Hydrogen chloride [kg, (%)] | 239,067 | 3,568 | 22,468 (9.4) | 25,982 (10.9) | 21,686 (9.1) | 10,813 (4.5) | 1,204 (0.5) | 1,115 (0.5) | 12,496 (5.2) | 9,765 (4.1) | 11,818 (4.9) |
| Pb [kg, (%)] | 10,183 | 208 | 223 (2.2) | 1,507 (14.8) | 338 (3.3) | 1,184 (11.6) | 9 (0.1) | -  (  -  ) | 0 (0.0) | 0 (0.0) | 21 (0.2) |
| Hg [kg, (%)] | 3.4 | 0.9 | -  (  -  ) | 0 (0.0) | 0.7 (19.8) | 1.1 (31.4) | -  (  -  ) | -  (  -  ) | -  (  -  ) | -  (  -  ) | -  (  -  ) |
| Ni [kg, (%)] | 12,218 | 204 | 31 (0.3) | 7 (0.1) | 729 (6.0) | 2,469 (20.2) | 58 (0.5) | 0 (0.0) | 17 (0.1) | 653 (5.3) | 4,999 (40.9) |
| As [kg, (%)] | 94 | 6 | 0 (0.0) | 49 (52.5) | 0 (0.0) | 3 (3.1) | -  (  -  ) | 0 (0.0) | 0 (0.0) | -  (  -  ) | -  (  -  ) |
| Cd [kg, (%)] | 113 | 9 | 28 (24.6) | 11 (9.4) | 7 (5.8) | 0 (0.0) | 0 (0.0) | -  (  -  ) | -  (  -  ) | -  (  -  ) | 0 (0.0) |
| Cr [kg, (%)] | 11,424 | 184 | 10 (0.1) | 17 (0.2) | 442 (3.9) | 381 (3.3) | 15 (0.1) | -  (  -  ) | 8 (0.1) | 297 (2.6) | 7,230 (63.3) |
| Mn [kg, (%)] | 35,745 | 701 | 10,691 (29.9) | 164 (0.5) | 208 (0.6) | 82 (0.2) | 9 (0.0) | -  (  -  ) | 0 (0.0) | 3,776 (10.6) | 7,321 (20.5) |
| Dibutyl phthalate [kg, (%)] | 1,811 | 226 | 1,255 (69.3) | -  (  -  ) | 0 (0.0) | 4 (0.2) | 1 (0.0) | -  (  -  ) | 0 (0.0) | -  (  -  ) | -  (  -  ) |
| Benzylbutylphthalate [kg, (%)] | 657 | 131 | 12 (1.9) | 2 (0.3) | -  (  -  ) | 0 (0.0) | 395 (60.1) | -  (  -  ) | -  (  -  ) | -  (  -  ) | -  (  -  ) |
| Bis (2-ethylhexyl) phthalate [kg, (%)] | 29,251 | 696 | 4,519 (15.4) | -  (  -  ) | 3,441 (11.8) | 941 (3.2) | 12,658 (43.3) | -  (  -  ) | 65 (0.2) | -  (  -  ) | 580 (2.0) |

Table S2 Average annual ambient concentrations of criteria air pollutants

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Pollutants** | **Reference values** | **National average** | **Ulsan** | **Sihwa/Banwol** | **Chungju/Daesan** | **Gwangyang Bay area** | **Pohang** |
| Nam-gu | Ulju-gun | Ansan-si | Siheung-si | Chungju-si | Seosan-si | Yeosu-si | Gwangyang-si | Pohang-si |
| SO2 (ppm) | Annual average ≤0.02 ppm | 0.005 | 0.008 | 0.009 | 0.006 | 0.008 | 0.004 | 0.005 | 0.007 | 0.007 | 0.006 |
| CO (ppm) | 8 hr average ≤9 ppm | 0.5 | 0.55 | 0.43 | 0.59 | 0.6 | 0.52 | 0.53 | 0.55 | 0.41 | 0.56 |
| O3 (ppm) | 8 hr average ≤0.06 ppm | 0.026 | 0.026 | 0.027 | 0.025 | 0.024 | 0.024 | 0.029 | 0.03 | 0.029 | 0.029 |
| NO2 (ppm) | Annual average ≤0.03 ppm | 0.023 | 0.026 | 0.02 | 0.032 | 0.033 | 0.024 | 0.018 | 0.019 | 0.015 | 0.016 |
| PM10 (μg/m3) | Annual average ≤50 ㎍/㎥ | 47.4 | 46.3 | 44 | 51.5 | 54.9 | 58 | 39.4 | 35.9 | 42.1 | 46.6 |

Table S3 Average annual concentrations of pollutants (2013-2015)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Pollutants** | **Reference value** | **Ulsan** | **Banwol** | **Pohang** | **Yeosu** | **Chungju** | **Daesan** |
| Yeochun-dong | Deoksin-ri | Wonsi-dong | Jangheung-dong | Yeochun-dong | Songjung-dong | Dokgot-ri |
| Pb | Annual average ≤0.5 μg/m3c | 0.034 | 0.045 | 0.075 | 0.03 | 0.02 | 0.024 | 0.038 |
| Cd | Annual average ≤0.005 μg/m3cb | 0.0005 | 0.0013 | 0.0019 | 0.0003 | 0.0002 | 0.0009 | 0.0006 |
| Cr | - | 0.006 | 0.002 | 0.011 | 0.012 | 0.001 | 0.002 | 0.002 |
| Cu | - | 0.018 | 0.021 | 0.088 | 0.024 | 0.009 | 0.017 | 0.008 |
| Mn | Annual average ≤0.15 μg/m3cb | 0.094 | 0.039 | 0.051 | 0.167 | 0.03 | 0.026 | 0.021 |
| Fe | - | 1.4 | 0.7 | 0.9 | 2.2 | 0.7 | 0.6 | 0.4 |
| Ni | Annual average ≤0.02 μg/m3c | 0.009 | 0.004 | 0.008 | 0.007 | 0.004 | 0.008 | 0.005 |
| As | Annual average ≤0.006 μg/m3c | 0.004 | 0.008 | 0.004 | 0.001 | 0.003 | 0.003 | 0.003 |
| Benzene | Annual average ≤1.57 ppba | 2.35 | 0.27 | 0.38 | 0.3 | 0.54 | 0.46 | 0.61 |
| Toluene | Weekly average ≤68.99 ppbb | 7.9 | 2.7 | 1.8 | 0.5 | 0.4 | 3.8 | 1.3 |
| Ethylbenzene | - | 4.1 | 0.4 | 0.4 | 0.1 | 0.1 | 0.7 | 0.9 |
| m,p-Xylene | - | 9.3 | 0.4 | 0.7 | 0.1 | 0.1 | 0.6 | 0.8 |
| Styrene | Weekly average ≤61.04 ppbb | 0.8 | 0.06 | 0.05 | 0.01 | 0.05 | 0.08 | 0.29 |
| o-Xylene | - | 3.16 | 0.16 | 0.25 | 0.05 | 0.05 | 0.33 | 0.24 |
| Chloroform | - | 0.1 | 0.04 | 0.02 | 0.03 | 0.01 | 0.12 | 0.02 |
| 1,1,1-Trichloroethane | - | 0 | 0.01 | 0 | 0 | 0 | 0 | 0 |
| Trichloroethylene | No safe levelb | 0.05 | 0.19 | 0.04 | 0.01 | 0.01 | 0.12 | 0.03 |
| Tetrachloroethylene | Annual average ≤36.86 ppbb | 0.48 | 0.02 | 0.01 | 0 | 0 | 0.01 | 0 |
| 1,1-Dichloroethane | - | 0.01 | 0 | 0 | 0.01 | 0 | 0.04 | 0 |
| Carbon tetrachloride | - | 0.1 | 0.05 | 0.06 | 0.06 | 0.01 | 0.07 | 0.04 |
| 1,3-Butadiene | No definitive conclusions | 0.37 | 0 | 0.08 | 0.13 | 0.3 | 0.07 | 0.24 |
| Benzo(a)anthracene | No specific guideline value | 0.29 | 0.6 | 0.3 | 0.48 | 0.36 | 0.4 | 0.26 |
| Chrysene | No safe level b | 0.57 | 0.86 | 0.59 | 0.94 | 0.63 | 0.7 | 0.55 |
| Benzo(b)fluoranthene |  | 0.39 | 0.74 | 0.43 | 0.76 | 0.51 | 0.58 | 0.43 |
| Benzo(k)fluoranthene |  | 0.16 | 0.23 | 0.17 | 0.3 | 0.21 | 0.23 | 0.17 |
| Dibenz(a,h)anthracene |  | 0.15 | 0.1 | 0.12 | 0.18 | 0.13 | 0.13 | 0.12 |
| Indeno(1,2,3-cd)pyrene |  | 0.24 | 0.43 | 0.19 | 0.37 | 0.26 | 0.33 | 0.23 |
| Benzo(a)pyrene | 1 ng/m3 d | 0.23 | 0.29 | 0.28 | 0.5 | 0.39 | 0.4 | 0.3 |

a: Attached table of article 2 of Enforcement Decree of the Framework Act on Environmental Policy of Republic of Korea

b: Air quality guidelines for Europe. 2nd ed.

c: EU target value. Air quality in Europe. 2015.

d: European Union. Directive 2004/107/EC relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. Target value of Benzoic(a)pyrene of air quality directive. 2004.

Table S4 Measured mean concentrations of ambient air pollutants

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Pollutants** | **Reference value** | **Ulsan** | **Sihwa/Banwol** | **Chungju/Daesan** | **Gwangyang Bay area** | **Pohang** |
| Hwasan-ri | Bugok-dong | Sansan-dong | Sinjung-dong | Moogu-dong | Choji high school | Choji commercial | Moojin apartment | Seochon elementary school | Siheun City Hall | Dokgot-ri | Daejuk-ri | Daesan-eup | Taein-dong | Geumho-dong | Haesan-dong | Jusam-dong | Myodo-dong | Chungrim-dong | Yunil-dong | Haedo-dong | Heunghae-eup |
| Onsan IC | Ulsan IC | Residential-comercial | Residential | Residential-control | Near residential | Near residential | Near residential | Near residential | Control | Industrial | Industrial | Residential-control | Near residential | Near residential | Near residential | Near residential | Near industrial | Industrial | Industrial | Residential | Control |
| Formaldehyde (ppb) | - | 2.63 | 4.49 | 3.32 | 3.66 | 3.37 | 5.58 | 6.7 | 5.92 | 6.85 | 6.5 | 5.84 | 3.52 | 2.9 | 4.51 | 4.24 | 6.11 | 6.25 | 4.52 | 2.58 | 2.21 | 2.45 | 1.88 |
| Acetaldehyde (ppb) | - | 1.41 | 2.79 | 1.6 | 1.88 | 1.49 | 4.54 | 3.77 | 4.47 | 5.31 | 4.58 | 2.84 | 2.32 | 2.21 | 3.14 | 2.46 | 3.88 | 3.63 | 2.95 | 1.3 | 1.24 | 1.28 | 1.18 |
| Benzene (ppb) | Annual ≤1.57 ppba | 1.25 | 1.81 | 0.34 | 0.33 | 0.31 | 0.53 | 0.52 | 0.49 | 0.39 | 0.34 | 1.13 | 0.77 | 0.41 | 0.65 | 1.17 | 0.63 | 0.63 | 0.61 | 0.63 | 0.41 | 0.39 | 0.27 |
| Ethylbenzene (ppb) | - | 1.07 | 1.24 | 0.45 | 0.27 | 0.31 | 0.58 | 0.77 | 1 | 0.74 | 0.4 | 0.62 | 0.37 | 0.21 | 0.22 | 0.25 | 0.27 | 0.28 | 0.16 | 0.28 | 0.27 | 0.24 | 0.09 |
| Vinyl chloride (ppb) | - | N.D | N.D | N.D | N.D | N.D | N.D | N.D | N.D | N.D | N.D | <0.01 | <0.01 | <0.01 | N.D | N.D | 0.03 | 0.06 | N.D | N.D | N.D | N.D | N.D |
| Trichloroethylene (ppb) | No safe levelb | 0.11 | 0.57 | 0.04 | 0.04 | 0.04 | 0.36 | 0.52 | 0.56 | 0.41 | 0.27 | 0.05 | 0.05 | 0.03 | 0.01 | 0.03 | <0.01 | 0.04 | 0.02 | 0.04 | 0.03 | 0.02 | <0.01 |
| Styrene (ppb) | Weekly ≤61.04 ppbb | 0.06 | 16.68 | 0.07 | 0.04 | 0.03 | 0.1 | 0.14 | 0.2 | 0.16 | 0.12 | 1.71 | 0.24 | 0.03 | 0.13 | 0.08 | 0.13 | 0.15 | 0.11 | 0.04 | 0.04 | 0.03 | 0.02 |
| 1,3-butadiene (ppb) | No definitive conclusionsb | <0.01 | 0.16 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | N.D | 0.06 | 0.01 | <0.01 | <0.01 | N.D | 0.03 | 0.11 | N.D | <0.01 | <0.01 | <0.01 | <0.01 |
| Phenol (ppb) | - | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | <0.01 | 0.01 | N.D | N.D | 0.01 | 0.17 | 0.14 | 0.16 | 0.02 | 0.06 | 0.02 | 0.03 | 0.02 | 0.03 | 0.01 | <0.01 | <0.01 |
| Xylene (m-, p-) (ppb) | - | 2.29 | 1.82 | 0.96 | 0.49 | 0.53 | 0.73 | 0.86 | 1.06 | 1 | 0.42 | 0.94 | 0.51 | 0.28 | 0.21 | 0.18 | 0.24 | 0.22 | 0.14 | 0.48 | 0.41 | 0.67 | 0.11 |
| Xylene(o-) (ppb) | - | 0.61 | 0.67 | 0.3 | 0.15 | 0.18 | 0.33 | 0.37 | 0.48 | 0.44 | 0.21 | 0.33 | 0.18 | 0.1 | 0.12 | 0.11 | 0.18 | 0.16 | 0.09 | 0.18 | 0.14 | 0.25 | 0.04 |
| Pb (ng/㎥) | Annual ≤500 ng/㎥a | 553.9 | 81.3 | 42.4 | 47.9 | 33.5 | 23.4 | 51 | 48.3 | 46.6 | 24.8 | 34.2 | 52 | 26.8 | 35.7 | 39.7 | 36.4 | 37.7 | 52.2 | 83.8 | 52.6 | 54.4 | 33.7 |
| Ni (ng/㎥) | Annual ≤20 ng/㎥c | 39.3 | 41.8 | 6.5 | 6 | 5.6 | 1.7 | 4.7 | 2.8 | 6.7 | 2.8 | 8.4 | 9.5 | 3.8 | 22 | 22.5 | 12.2 | 15 | 25.6 | 26.4 | 10.5 | 6 | 3.7 |
| As (ng/㎥) | Annual ≤6 ng/㎥c | 83.3 | 10.2 | 4.4 | 4.5 | 4.3 | 1.7 | 2 | 0.9 | 1.4 | 1 | 3.2 | 3.1 | 3.1 | 11 | 11.2 | 5.7 | 7.9 | 9.8 | 12 | 8.4 | 9.6 | 8.5 |
| Cd (ng/㎥) | Annual ≤5 ng/㎥b | 15.5 | 3.2 | 1.5 | 1.6 | 1.4 | 1.7 | 1.6 | 0.6 | 1.1 | 0.8 | 0.9 | 0.5 | 0.5 | 0.5 | 0.6 | 0.5 | 0.7 | 0.8 | 1.6 | 1.1 | 1 | 0.8 |
| Cr (ng/㎥) | - | 35.2 | 43.3 | 6.2 | 11 | 5.8 | 4.9 | 6.6 | 5.2 | 6.4 | 4.6 | 6.9 | 5.1 | 3.3 | 47.4 | 48.7 | 9.9 | 10.4 | 19.3 | 115.2 | 21.5 | 18.2 | 13 |
| Mn (ng/㎥) | Annual ≤150 ng/㎥b | 153.8 | 185.3 | 53.5 | 50.7 | 49.5 | - | - | - | - | - | 32.1 | 55.3 | 19.1 | 56.1 | 54.5 | 34.9 | 41 | 48.3 | 564.1 | 123.9 | 72 | 38.3 |
| Dibutyl phthalate (ng/㎥) | - | 16.7 | 18.6 | 29.9 | 18 | 25.3 | 16.08 | 12.24 | 22.71 | 10.81 | 16.95 | 148.85 | 60.27 | 82.8 | 3.07 | 2.97 | 3.14 | 4.89 | 2.96 | 110.4 | 106.6 | 124.9 | 91.3 |
| Benzylbutylphthalate (ng/㎥) | - | 0.3 | 0.3 | 0.6 | 0.5 | 3.1 | 1.04 | 2.75 | 1 | 1.53 | 1.57 | 3.11 | 3.47 | 2.97 | 0.33 | 0.17 | 0.09 | 0.22 | 0.16 | 50.8 | 4.2 | 8.1 | 4 |
| Bis(2-ethyl hexyl) phthalate (ng/㎥) | - | 71.3 | 46.2 | 109.3 | 53 | 79.8 | 61.91 | 61.34 | 76.09 | 65.64 | 56.8 | 169.41 | 176.63 | 160.41 | 23.83 | 15.46 | 33.46 | 23.4 | 21.66 | 224.7 | 177.5 | 296.2 | 168.2 |
| Naphthalene (ng/㎥) | No specific guideline value (as low as possible)b | 0.3 | 0.26 | 0.23 | 0.26 | 0.45 | 0.22 | 0.17 | 0.17 | 0.15 | 0.16 | 0.13 | 0.09 | 0.08 | 0.31 | 0.12 | 0.27 | 0.29 | 0.13 | 0.32 | 0.15 | 0.17 | 0.14 |
| Pyrene (ng/㎥) | 0.78 | 0.64 | 0.68 | 0.76 | 1.08 | 0.36 | 0.35 | 0.33 | 0.51 | 0.24 | 0.64 | 0.48 | 0.61 | 0.72 | 0.28 | 0.37 | 0.43 | 0.79 | 2.02 | 0.49 | 0.61 | 0.6 |
| Fluorene (ng/㎥) | 0.17 | 0.12 | 0.08 | 0.09 | 0.17 | 0.05 | 0.06 | 0.09 | 0.06 | 0.02 | 0.05 | 0.05 | 0.06 | 0.28 | 0.04 | 0.2 | 0.25 | 0.1 | 0.2 | 0.1 | 0.09 | 0.09 |
| Phenanthrene (ng/㎥) | 0.62 | 0.49 | 0.5 | 0.56 | 0.88 | 0.32 | 0.24 | 0.21 | 0.32 | 0.18 | 0.37 | 0.33 | 0.39 | 0.75 | 0.39 | 0.46 | 0.73 | 0.82 | 1.37 | 0.55 | 0.58 | 0.55 |

a: Attached table of article 2 of Enforcement Decree of the Framework Act on Environmental Policy of Republic of Korea

b: Air Quality Guidelines for Europe. 2nd Ed.

c: European Environmental Agency. EU target value. Air quality in Europe. 2015

Table S5 Geometric mean concentrations of exposure biomarkers and proportion (%) of participants with absorbed pollutant concentration higher than the reference value

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Pollutants | **Reference valuea** | **Ulsan** | **Sihwa/Banwol** | **Chungju/Daesan** | **Gwangyang Bay area** | **Pohang** |
| Siheung-si | Ansan-si | Chungju-si | Seosan-si | Gwangyang-si | Yeosu-si |
| Exposure | Control | Exposure | Control | Exposure | Control | Exposure | Control | Exposure | Control | Exposure | Control | Exposure | Control | Exposure | Control |
| Blood Pb (㎍/dL) | 1.94 | 2.27\* (64.0) | 1.96 (50.2) | 1.92\* (52.3) | 1.68 (39.3) | 1.94 (51.0) | 1.89 (53.9) | 1.50\* (31.6) | 1.36 (23.0) | 1.81 (46.3) | 1.73 (39.0) | 1.92 (52.3) | 1.9 (48.3) | 1.7 (40.6) | 1.77 (42.9) | 1.80\* (47.2) | 1.61 (36.4) |
| Urinary Cd (㎍/g Cr) | 0.5 | 0.93\* (78.0) | 0.75 (73.3) | 0.74 (70.4) | 0.7 (70.8) | 0.78 (73.0) | 0.79 (73.5) | 0.61 (64.0) | 0.61 (62.6) | 1.61 (93.2) | 1.4 (90.2) | 0.88\* (76.7) | 0.73 (66.7) | 0.93 (75.3) | 0.89 (76.0) | 1.39 (85.1) | 1.52 (86.6) |
| Urinary Hg (㎍/g Cr) | 0.49 | 0.65\* (65.0) | 0.57 (58.9) | 0.42 (42.3) | 0.39 (38.7) | 0.42 (41.2) | 0.47 (50.8) | 0.4 (38.6) | 0.47\* (47.9) | 0.46 (50.5) | 0.38 (40.2) | 0.42 (40.7) | 0.37 (35.1) | 0.37 (36.3) | 0.53\* (54.2) | 1.01 (75.2) | 1.04 (76.6) |
| Urinary PGA (㎍/g Cr) | 214 | 203.6\* (46.2) | 168.9 (39.9) | 219.7\* (54.6) | 189.8 (44.3) | 232.4 (59.1) | 280.6 (56.6) | 168.1 (40.1) | 168.3 (36.6) | 175.2 (37.2) | 161.3 (40.2) | 205.8\* (51.4) | 146.2 (46.9) | 212.4 (54.9) | 223.3 (60.9) | 246 (55.2) | 323.2\* (61.6) |
| Urinary t,t-MA (㎍/g Cr) | 81.2 | 37.6\* (25.3) | 30.9 (15.3) | 56.9 (32.9) | 59.8 (32.5) | 56.4 (32.0) | 75.5\* (45.6) | 49.3 (28.6) | 50.5 (23.4) | 41.6\* (19.7) | 34.2 (14.7) | 68.3 (41.4) | 85.8\* (52.2) | 60.3 (36.5) | 56.1 (35.6) | 54.6 (35.3) | 68.0\* (45.1) |
| Urinary MHA (㎍/g Cr) | 318 | 412.1 (59.2) | 446.9 (58.4) | 400.1 (60.2) | 442.5 (61.1) | 390.3 (58.8) | 471 (63.2) | 278.4\* (39.2) | 235.8 (33.8) | 296.4 (45.2) | 236 (37.5) | 358.7 (57.2) | 443.7\* (65.9) | 357.3 (58.9) | 391.5 (58.6) | 245.9 (36.6) | 242.8 (38.7) |
| Urinary m-MHA (㎍/g Cr) | - | 94.0\* ( - ) | 71.9 ( - ) | 156.7 ( - ) | 140.5 ( - ) | 177.8 ( - ) | 194.8 ( - ) | 110.9\* ( - ) | 89.6 ( - ) | 111.6 ( - ) | 91.7 ( - ) | 155 ( - ) | 211.4\* ( - ) | 103 ( - ) | 158.6\* ( - ) | 142.4\* ( - ) | 113.9 ( - ) |
| Urinary p-MHA (㎍/g Cr) | - | 77.1\* ( - ) | 64.6 ( - ) | 72.7 ( - ) | 71.2 ( - ) | 58.9 ( - ) | 84.1\* ( - ) | 65.1 ( - ) | 57.1 ( - ) | 74.6 ( - ) | 59.3 ( - ) | 57.9 ( - ) | 66.1\* ( - ) | 66.7 ( - ) | 75.1 ( - ) | 71.9 ( - ) | 66.3 ( - ) |
| Urinary o-MHA (㎍/g Cr) | - | 61.8\* ( - ) | 47.5 ( - ) | 79.8 ( - ) | 94.1 ( - ) | 67.6 ( - ) | 87 ( - ) | 58.1 ( - ) | 47.7 ( - ) | 62.9 ( - ) | 52.2 ( - ) | 73.4 ( - ) | 79.0\* ( - ) | 57 ( - ) | 73.7\* ( - ) | 22.1 ( - ) | 15 ( - ) |
| Urinary HA (mg/g Cr) | 168 | 182.3 (56.7) | 184.1 (56.2) | 184.9 (55.5) | 183.5 (55.6) | 180.9 (53.3) | 229.6\* (65.4) | 149.6 (51.4) | 160.8 (50.0) | 199.1 (56.7) | 185.1 (58.8) | 184.2 (60.1) | 172.4 (53.1) | 182.6 (57.6) | 181.7 (56.7) | 174.4 (56.2) | 200.2\* (62.2) |
| Urinary MA (㎍/g Cr) | 210 | 177.1\* (37.6) | 137.3 (26.3) | 212.2 (51.7) | 201.1 (47.7) | 211.5 (49.9) | 199.8 (48.9) | 207.7\* (46.5) | 166.7 (34.1) | 223.5 (44.0) | 233.6 (50.0) | 210.5 (50.2) | 283.6\* (66.2) | 240.4 (58.0) | 269.4\* (66.7) | 234.7 (52.1) | 235.9 (48.8) |
| Urinary 1-OHP (㎍/g Cr) | 0.2 | 0.10\* (33.1) | 0.07 (23.2) | 0.16 (41.3) | 0.23\* (51.9) | 0.12 (42.0) | 0.28\* (48.1) | 0.11 (29.6) | 0.12 (32.4) | 0.12\* (29.3) | 0.08 (13.9) | 0.17 (40.8) | 0.15 (40.4) | 0.14 (40.9) | 0.17\* (44.2) | 0.20\* (52.4) | 0.15 (43.2) |
| Urinary 2-naphthol (㎍/g Cr) | 3.07 | 3.0\* (49.0) | 1.4 (28.6) | 2 (39.1) | 2.2 (36.5) | 2.4 (39.7) | 1.9 (40.7) | 2.4 (39.4) | 2.5 (39.3) | 2.6 (37.2) | 2.2 (30.9) | 6.6\* (76.9) | 4.5 (67.5) | 7.3 (82.6) | 7.9 (79.9) | 3.6 (54.5) | 3.8 (54.3) |
| Urinary 2-HF (㎍/g Cr) | 0.37 | 0.27\* (41.8) | 0.14 (32.5) | 0.23 (41.1) | 0.47\* (63.6) | 0.17 (33.1) | 0.30\* (47.3) | 0.25 (40.3) | 0.23 (38.4) | 0.28 (42.3) | 0.35 (47.9) | 0.36\* (57.6) | 0.14 (37.0) | 0.31 (50.8) | 0.37 (56.7) | 0.27 (40.2) | 0.26 (43.4) |
| Urinary 1-HPH (㎍/g Cr) | 0.12 | 0.10\* (40.6) | 0.06 (24.3) | 0.09 (46.5) | 0.09 (41.2) | 0.07 (38.1) | 0.13\* (51.7) | 0.07 (29.4) | 0.07 (33.1) | 0.1 (42.0) | 0.08 (37.0) | 0.12 (50.2) | 0.09 (53.9) | 0.11 (49.0) | 0.1 (46.8) | 0.09\* (44.5) | 0.08 (34.6) |
| Urinary MnBP (㎍/g Cr) | 32.4 | 20.6 (28.4) | 20.3 (26.7) | 14.6\* (40.5) | 9.1 (33.9) | 5.2 (18.7) | 25.1\* (42.6) | 25.4 (40.7) | 23.4 (30.3) | 26.1\* (39.3) | 19.1 (32.4) | 29.3 (45.8) | 25.8 (35.5) | 27 (40.4) | 39.3\* (61.9) | 28.6 (43.5) | 42.1\* (61.8) |
| Urinary MBzP (㎍/g Cr) | 3.73 | 2.03 (32.9) | 1.95 (30.2) | 1.22\* (19.7) | 0.86 (16.7) | 0.68 (10.9) | 1.85\* (30.9) | 3.51\* (50.0) | 2.6 (43.4) | 3.34\* (47.0) | 2.49 (35.3) | 7.26\* (80.6) | 6.16 (70.2) | 5.48 (75.2) | 6.11 (77.6) | 2.56 (39.7) | 4.04\* (55.1) |
| Urinary MEOHP (㎍/g Cr) | 16.7 | 8.9\* (21.0) | 8 (17.1) | 6.1\* (24.2) | 3.9 (13.8) | 2.8 (12.8) | 11.0\* (29.4) | 11.4 (29.1) | 10.3 (24.8) | 11.9\* (29.5) | 8.6 (17.6) | 18.5 (52.9) | 17.3 (44.7) | 15.9 (51.5) | 18.3\* (61.3) | 11.1 (27.5) | 17.8\* (49.2) |
| Urinary MEHHP (㎍/g Cr) | 24.2 | 14.9\* (23.7) | 13 (16.7) | 10.6\* (32.4) | 7 (20.7) | 4.7 (16.6) | 18.3\* (36.8) | 18.1 (33.5) | 16.7 (26.9) | 20.5\* (37.6) | 13.4 (17.6) | 26.6 (53.2) | 26.1 (47.8) | 25.3 (55.9) | 28.7\* (63.9) | 16.9 (28.8) | 25.7\* (52.5) |
| Urinary MECPP (㎍/g Cr) | 27.1 | 16.7\* (28.6) | 15.2 (19.9) | 7.6\* (25.1) | 6 (20.1) | 3.9 (13.1) | 20.0\* (38.3) | 21.5\* (36.4) | 18.8 (24.1) | 22.9\* (33.2) | 15.3 (18.6) | 29.2 (50.5) | 29.2 (50.4) | 24.4 (47.0) | 29.0\* (54.4) | 19.3 (30.2) | 26.5\* (49.1) |

\*P<0.05 and sample geometric mean was higher than control group. P-value was calculated using Wilcoxon rank-sum test.

a: Geometric means from the 2nd stage National Environmental Health Survey

PGA: phenylglyoxylic acid, t,t-MA: t,t-muconic acid, MHA: methylhippuric acid, HA: hippuric acid, MA: mandelic acid, 1-OHP: 1-hydroxypyrene, 2-HF: 2-hydroxyfluorene, 1-HPH: 1-hydroxyphenanthrene, MnBP: monobutyl phthalate, MBzP : monobenzyl phthalate, MEOHP: mono-(2-ethyl-5-oxohexyl)phthalate, MEHHP: mono-(2-ethyl-5-hydroxy-hexyl)phthalate, MECPP: mono(2-ethyl-5-carboxypentyl)phthalate