

Table S1. Comparison of metal fractionation results obtained for SSA and FB using standard amounts of reagents for sequential extraction (BCR model) and twice smaller amounts (modification)

| Material | Amount of reagents | Fraction | Fe [mg/kg] | Zn [mg/kg] | Cd [mg/kg] | Cu [mg/kg] | Ni [mg/kg] | Mn [mg/kg] | Cr [mg/kg] | Al. [mg/kg] | Pb [mg/kg] |
|---------------|--------------------|----------|--------------|-------------|---------------|-------------|--------------|-------------|-------------|-------------|------------|
| I-SSA | 2x smaller amount | F1 | < 11 | 297 ± 19 | < 0.83 | 67.8 ± 1.9 | 4.93 ± 0.14 | 110.5 ± 6.7 | < 0.30 | < 16 | < 0.45 |
| I-SSA | 2x smaller amount | F2 | 35.0 ± 2.0 | 275 ± 18 | 0.92 ± 0.11 | 184 ± 11 | 11.43 ± 0.10 | 259.0 ± 1.0 | < 0.30 | < 16 | < 0.45 |
| I-SSA | 2x smaller amount | F3 | < 3.3 | 20.4 ± 4.1 | < 0.83 | 19.7 ± 1.5 | 2.74 ± 0.32 | 29.6 ± 6.1 | < 0.98 | < 5.0 | < 0.45 |
| I-SSA | 2x smaller amount | F4 | 59600 ± 1300 | 1710 ± 52 | 4.82 ± 0.11 | 824 ± 18 | < 0.41 | 365 ± 10 | 183.0 ± 9.8 | 50480 ± 950 | 36.3 ± 1.5 |
| I-SSA | Standard BCR model | F1 | < 22 | 385 ± 36 | < 1.7 | 141.1 ± 7.6 | 9.28 ± 0.21 | 210.0 ± 4.0 | < 0.60 | < 32 | < 0.90 |
| I-SSA | Standard BCR model | F2 | 166 ± 11 | 410 ± 44 | < 1.7 | 179.3 ± 5.4 | 10.49 ± 0.34 | 222.5 ± 7.5 | < 0.60 | 36.8 ± 4.6 | < 0.90 |
| I-SSA | Standard BCR model | F3 | < 6.6 | 36.1 ± 6.2 | < 1.7 | 28.3 ± 4.0 | 2.97 ± 0.23 | 25.0 ± 3.3 | < 2.0 | < 32 | < 0.90 |
| I-SSA | Standard BCR model | F4 | 59800 ± 400 | 1263 ± 26 | 4.910 ± 0.020 | 740 ± 26 | < 0.82 | 311.6 ± 4.3 | 186.3 ± 7.7 | 50370 ± 470 | 37.2 ± 1.9 |
| Fluidized bed | 2x smaller amount | F1 | < 11 | 130.7 ± 6.4 | 0.870 ± 0.020 | 37.4 ± 2.2 | 4.11 ± 0.43 | 97.4 ± 4.2 | < 0.30 | < 16 | < 0.45 |
| Fluidized bed | 2x smaller amount | F2 | 81.1 ± 3.3 | 44.4 ± 3.0 | < 0.83 | 12.0 ± 2.4 | < 1.4 | 19.5 ± 2.6 | < 0.30 | 41.7 ± 4.7 | < 0.45 |
| Fluidized bed | 2x smaller amount | F3 | < 3.3 | < 9.7 | < 0.83 | 2.1 ± 1.1 | < 1.4 | 4.2 ± 1.4 | < 0.98 | < 5.0 | < 1.5 |
| Fluidized bed | 2x smaller amount | F4 | 24300 ± 1100 | 512 ± 83 | < 0.83 | 94.6 ± 2.8 | < 0.41 | 136.8 ± 4.7 | 114.6 ± 8.5 | 12780 ± 370 | 26.6 ± 3.2 |
| Fluidized bed | Standard BCR model | F1 | 23.4 ± 4.9 | 158 ± 13 | < 1.7 | 42.4 ± 2.9 | 4.58 ± 0.53 | 106.7 ± 4.4 | < 0.60 | 69.4 ± 3.8 | < 0.90 |
| Fluidized bed | Standard BCR model | F2 | 154.5 ± 5.2 | 33.5 ± 9.7 | < 1.7 | 15.0 ± 2.3 | < 2.8 | 20.4 ± 1.0 | < 0.60 | 178.9 ± 8.3 | < 0.90 |
| Fluidized bed | Standard BCR model | F3 | < 6.6 | < 5.8 | < 1.7 | 3.3 ± 1.2 | < 2.8 | 5.4 ± 1.4 | < 2.0 | < 10 | < 0.90 |
| Fluidized bed | Standard BCR model | F4 | 24200 ± 900 | 493 ± 111 | < 0.50 | 88.6 ± 3.9 | < 0.82 | 128.7 ± 7.8 | 115 ± 8 | 12550 ± 160 | 26.6 ± 2.4 |

The MIP-OES technique is one of the modern spectrometric techniques characterized by high sensitivity to most metals, the possibility of determining many elements during one analysis, and low analysis costs due to the use of pure nitrogen as a plasma source. In this case plasma gas (nitrogen) can be obtained from the air using a compressor equipped with appropriate molecular sieves. It is a significant compromise between flame atomic absorption spectrometry (F-AAS) and electrothermal atomic absorption spectrometry (ET-AAS), which have many limitations, and the highly expensive inductively coupled plasma - mass spectrometry (ICP-MS) and inductively coupled plasma - optical emission

spectrometry (ICP-OES). The use of the described technique in elemental analysis brings many benefits and is in line with the principles of green analytical chemistry.

Table S2. Presentation of selected validation parameters of the methods used for the determination of heavy metals (MIP-OES technique)

| <i>Element</i> | <i>Wavelength [nm]</i> | <i>Calibration curve equation</i> | <i>Coefficient of determination (R^2)</i> | <i>LOD [mg/kg]</i> | <i>LOQ [mg/kg]</i> |
|------------------|------------------------|--------------------------------------|--|--------------------|--------------------|
| <i>Chromium</i> | 425.433 | $I = 4732.5124 \cdot C + 17.4998$ | 0.9998 | 0.30 | 0.98 |
| <i>Zinc</i> | 213.857 | $I = 6427.4757 \cdot C + 1896.0791$ | 0.9986 | 2.90 | 9.70 |
| <i>Aluminium</i> | 394.401 | $I = 4096.7266 \cdot C + 10349.0066$ | 0.9992 | 5.00 | 16.00 |
| <i>Cadmium</i> | 228.802 | $I = 13278.3979 \cdot C + 14.2457$ | 0.9997 | 0.25 | 0.83 |
| <i>Manganese</i> | 403.307 | $I = 16619.2712 \cdot C + 16.9282$ | 0.9999 | 0.19 | 0.63 |
| | 403.076 | $I = 25053.0881 \cdot C + 10.1911$ | 0.9999 | 0.26 | 0.82 |
| <i>Copper</i> | 324.754 | $I = 74480.8257 \cdot C + 482.1520$ | 0.9997 | 0.27 | 0.89 |
| | 327.395 | $I = 44382.9856 \cdot C + 178.4845$ | 0.9999 | 0.31 | 1.00 |
| <i>Nickel</i> | 352.454 | $I = 11475.1738 \cdot C - 47.9812$ | 0.9999 | 0.41 | 1.40 |
| <i>Lead</i> | 405.781 | $I = 2074.2240 \cdot C - 3.1355$ | 0.9987 | 0.45 | 1.50 |
| <i>Iron</i> | 371.993 | $I = 5445.2246 \cdot C - 1165.1406$ | 0.9995 | 3.30 | 11.00 |

Table S3. Validation parameters of the mercury determination method (CV-AAS technique)

| <i>Element</i> | <i>Wavelength [nm]</i> | <i>Calibration curve equation</i> | <i>Coefficient of determination (R^2)</i> | <i>LOD [μg/kg]</i> | <i>LOQ [μg/kg]</i> |
|----------------|------------------------|-----------------------------------|--|-----------------------------------|-----------------------------------|
| <i>Mercury</i> | 257.000 | $A = 0.68045 \cdot C + 0.00089$ | 0.9956 | 0.05 | 0.18 |

Table S4. Comparison of the content of mobile fractions of the tested metals in ashes from industrial installations and fluidized beds, and the concentration of these metals in Polish soils (Chief Inspectorate of Environmental Protection, 2020; Ronda et al., 2022)

| <i>Element</i> | <i>Highly mobile fraction content (F1 + F2) in I-SSA (mean \pm standard deviation) [mg/kg]</i> | <i>Highly mobile fraction content (F1 + F2) in fluidized bed (mean \pm standard deviation) [mg/kg]</i> | <i>Typical concentration in soil (Poland) [mg/kg]</i> |
|----------------|---|---|---|
|----------------|---|---|---|

| | | | |
|------------------|------------|-----------|------|
| <i>Chromium</i> | < 0.60 | < 0.60 | 12 |
| <i>Zinc</i> | 443 ± 231 | 365 ± 229 | 62 |
| <i>Aluminium</i> | < 44 | < 38 | 4300 |
| <i>Cadmium</i> | < 1.4 | < 0.80 | 0.65 |
| <i>Manganese</i> | 285 ± 42 | 117 ± 42 | 379 |
| <i>Copper</i> | 119 ± 46 | 73 ± 68 | 6.3 |
| <i>Nickel</i> | 14.7 ± 8.4 | < 6.6 | 9.7 |
| <i>Lead</i> | < 0.46 | < 0.46 | 29 |
| <i>Iron</i> | < 49 | 249 ± 119 | 3600 |



Figure S1. Diagram of the sequential metal extraction procedure used.

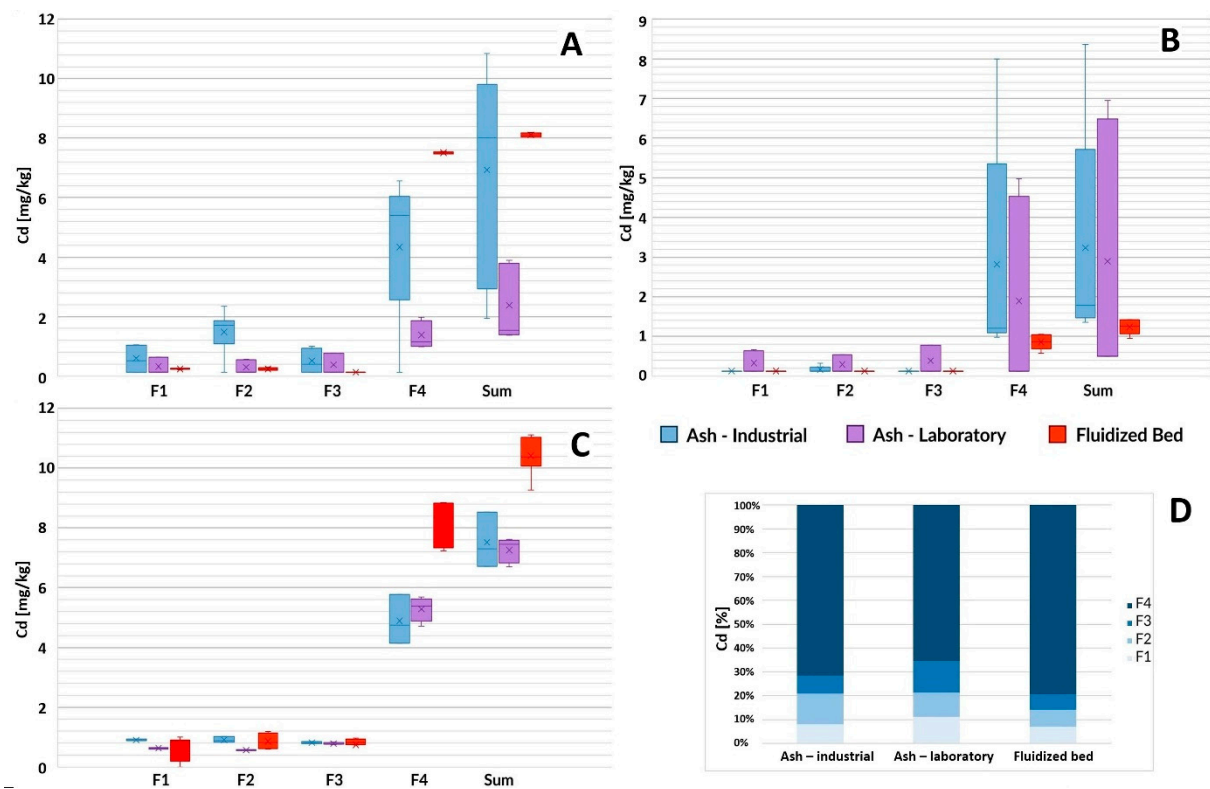


Figure S2. Cadmium content in ash samples from three wastewater treatment plants depending on the method of sludge incineration method (laboratory furnace or industrial installation) and in used fluidized beds. F1 – ion exchange and carbonate fraction. F2 – fraction associated with Mn and Fe oxides (reducible). F3 - organic and sulphide fraction. F4 - residual fraction. Sum – the total content of the element. A – GOŚ Lodz. B - Gdansk East. C – GOŚ Dębogórze. D – percentage fraction by type of material (average of all treatment plants).

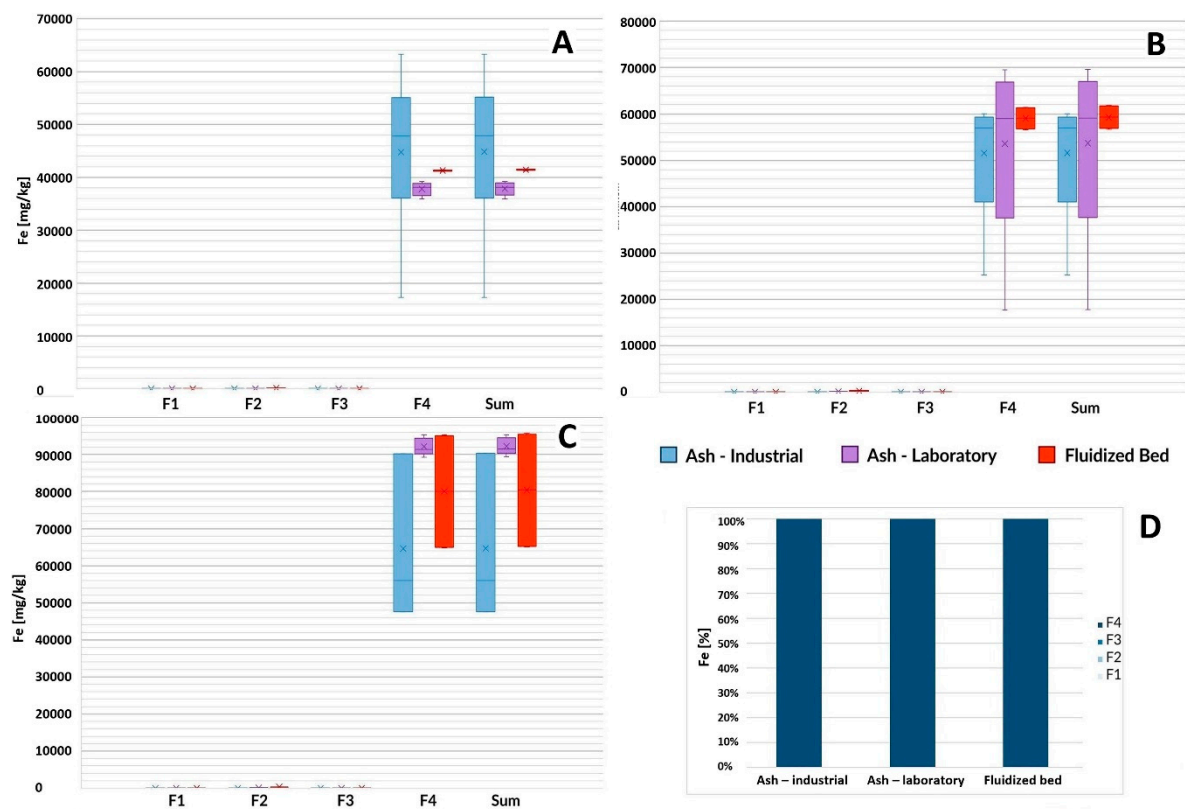


Figure S3. Iron content in ash samples from three wastewater treatment plants depending on the method of sludge incineration method (laboratory furnace or industrial installation) and in used fluidized beds. F1 – ion exchange and carbonate fraction. F2 – fraction associated with Mn and Fe oxides (reducible). F3 - organic and sulphide fraction. F4 - residual fraction. Sum – the total content of the element. A – GOŚ Lodz. B - Gdansk East. C – GOŚ Dębogórze. D – percentage fraction by type of material (average of all treatment plants).

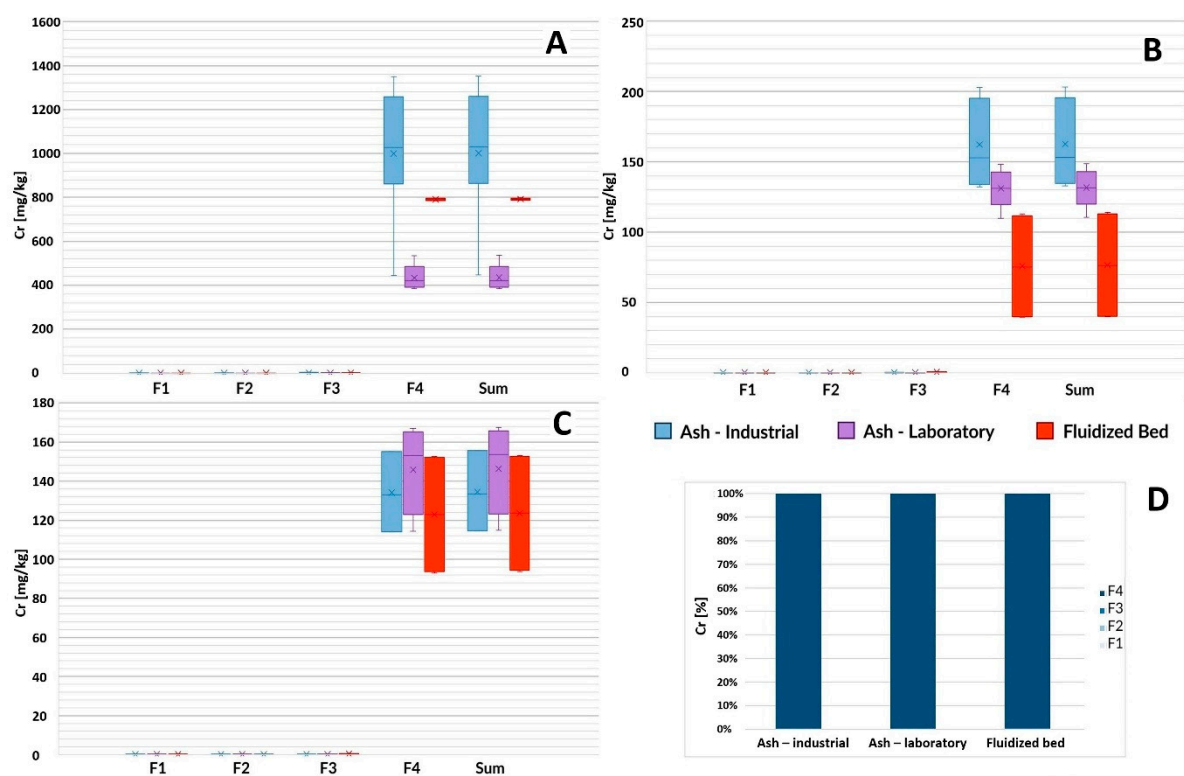


Figure S4. Chromium content in ash samples from three wastewater treatment plants depending on the method of sludge incineration method (laboratory furnace or industrial installation) and in used fluidized beds. F1 – ion exchange and carbonate fraction. F2 – fraction associated with Mn and Fe oxides (reducible). F3 - organic and sulphide fraction. F4 - residual fraction. Sum – the total content of the element. A – GOŚ Lodz. B - Gdansk East. C – GOŚ Dębogórze. D – percentage fraction by type of material (average of all treatment plants).

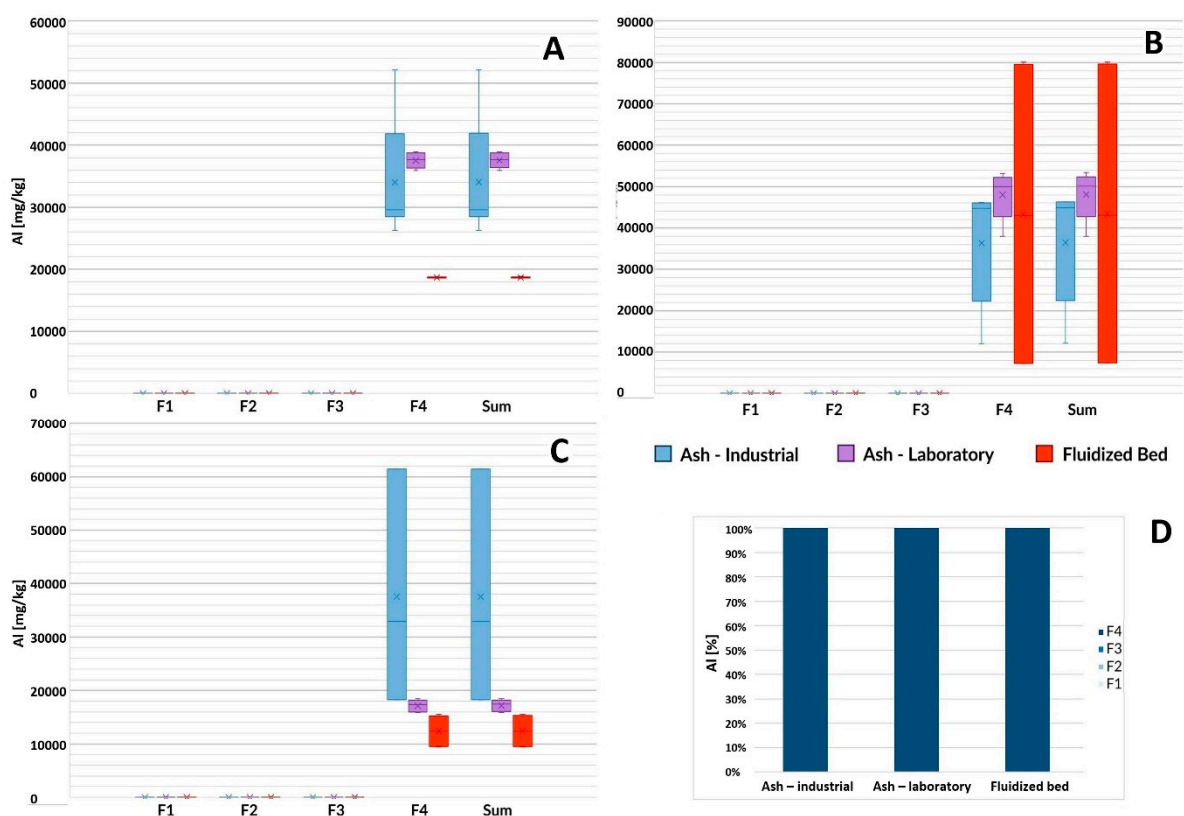


Figure S5. Aluminum content in ash samples from three wastewater treatment plants depending on the method of sludge incineration method (laboratory furnace or industrial installation) and in used fluidized beds. F1 – ion exchange and carbonate fraction. F2 – fraction associated with Mn and Fe oxides (reducible). F3 - organic and sulphide fraction. F4 - residual fraction. Sum – the total content of the element. A – GOŚ Lodz. B - Gdansk East. C – GOŚ Dębogórze. D – percentage fraction by type of material (average of all treatment plants).