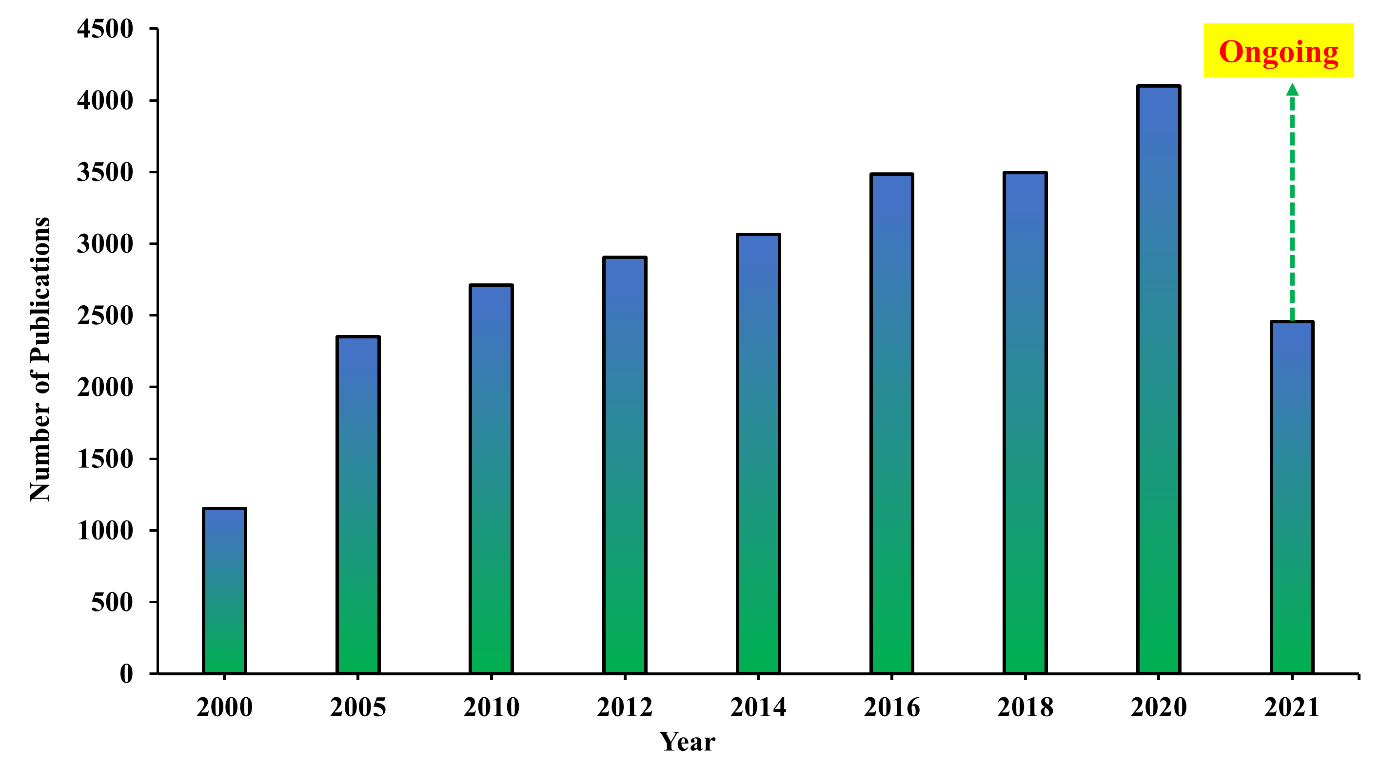
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| **Table 1 Metals contributed by different types of waste and their possible sources, highlighting major issues and solutions** | | | | | | |
| **S. No** | **Solid Waste** | **Metals** | **Metals sources** | **Major issues** | **Possible solutions** | **References** |
| 1 | Municipal | Cd, Cr, Cu, Hg, Ni, Pb, and Zn | Municipal Wastewater Treatment Plant | Environmental hazard and health risk | Knowledge on their total concentrations and chemical forms | [1] |
| 2 | Clinical | Hg, Pb, As, Cd | Pharmaceutical, chemical, and radioactive waste | Environmental pollution by landfill leachate and gas | Appropriate segregation and sorting of clinical waste at the generation site | [2] |
| 3 | Industrial | Pb | Sheets for buildings, ammunition | Environment deterioration, effects on humans, birds, animals | Increased collection and recycling | [3] |
| Hg | Chlor-alkali industry, measuring devices, and control equipment |
| Cd | Plating and coating, silver-cadmium alloys, PVC stabilizer |
| Cr | Stainless steel, plating, leather tanning |
| 4 | Residential/Domestic | Cd | Batteries and accumulators | No proper disposal often leads to tremendous environmental harm, recovery of metals not always done | Segregation and recovery of metals for future uses | [4] |
| Ni, | Nickel-chrome alloys in household heating appliances |
| Hg | Fluorescent lamps and thermometers |
| Zn | fluorescent lamps, cosmetics, medicines |
| Pb | Stibium-lead batteries |
| 5 | Agriculture | As | Pesticide residues, animal diets | Crop failure or diminished yields | Organic residue applications, application of animal manure | [5] |
| Cu | Hog rations | Plant growth inhibited; ruminants susceptible |
| Pb, Cd, Cr | Commercial fertilizers | accumulation in soils, plants and food chain and environment contamination | Proper identification of fertilizers components and after effects | [6] |

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| **Table 2 Microbial mediated metal remediation processes employing various bacteria, fungi, and algae in different mediums.** | | | | | | | |
| **S. No** | **Microorganisms** | **Types** | **Heavy Metals** | **Contaminated**  **sources** | **Mechanism** | **Reduction** | **References** |
| 1 | Sporosarcina pasteurii  Strain: DSM 33 | Bacteria | Pb  Zn  Cd | Soil | Microbially-induced carbonate precipitation | 33.3-85.9%  21.4 - 66.0%  13.6 - 29.9% | [7] |
| 2 | *Chlorella vulgaris* | Microalgae | Pb | Water | Biosorption | ~90% | [8] |
| 3 | *Sphingomonas desiccabilis*and, *Bacillus idriensis* | Bacteria | As | Soil | Biovolatilization | 2.2%–4.5% | [9] |
| 4 | *Acinetobacter calcium acetate, Pseudomonas putida and Salfobacillus* | Bacteria | Pb, Cu, Cr, Cd, Ni, V | Seawater | Physical precipitation, bio- deposition of heavy metals | 72.60% | [10] |
| 5 | *Penicillium citrinum* | Fungus | Cu  Mn  Zn | Coffee wastewater | Adsorption | 44%  62%  48% | [11] |
| 6 | *Mucor circinelloides, Actinomucor sp,*  *Mortierella sp* | Fungus | Zn  Pb  Mn | Mine tailings | Adsorption | 86.89%,  95.46%,  92.78% | [12] |
| 7 | *Fusarium oxysporum* | Fungus | Pb2+ Cd2+ | Water | Metal carbonate formation | NA | [13] |
| 8 | Brevundimonas species IITISM22 | Bacteria | Hg | Soil | Biosorption | 666.6 mg/g | [14] |
| 9 | *Alkalibacterium* sp. TRTYP6 | Bacteria | Cu | Municipal solid from waste landfill site | Bioleaching | 52% | [15] |
| 10 | *Acidithiobacilluscaldus, Leptospirillum ferriphilum, Sulfobacillus* spp *Ferroplasma spp* | Bacteria | Co  Ni  Li | Waste lithium-ion batteries (LIBs) | Bioleaching | 99.9%  99.7%  84% | [16] |
| 11 | *Acidithiobacillus ferrooxidans, Ferroplasma acidiphilum,* and *Leptospirillum ferriphilum* | Bacteria | Cu | Waste printed circuit boards (WPCBs) | Bioleaching | 76.2% | [17] |
| 12 | *Acidithiobacillus ferrooxidans* | Bacteria | Cu | Salobo mine waste | Bioleaching | NA | [18] |
| 13 | *Chromobacterium violaceum* | Bacteria | Au  Cu | Waste mobile phone printed circuit boards (PCBs) | Bioleaching | 11%  11.4% | [19] |
| 14 | *Acidithiobacilli* | Bacteria | Cd, Cu, Zn | Fly ash (originating from municipal solid waste incineration | Bioleaching | Mobilization >80% | [20] |
| 15 | Nanochloropsis, Pavlova lutheri, Tetraselmischuii and Chaetoceros muelleri | Microalgae | Al, Fe | Waste streams | Adsorption | >95% | [21] |
| 16 | Nostoc muscorum  Anabaena variabilis | Cyanobacteria | Pb | Aqueous solution | NA | 97.8%  71.4% | [22] |
| 17 | Nostoc commune, Oscillatoria limosa and Chlorella vulgaris | Microalgae | Cu,  Pb | Wastewater from a metal rolling mill industry | Bioconversion and absorption | 10%,  90% | [23] |
| 18 | *Bacillus megaterium* strain UM-123 | Bacteria | As | Soil in Miyazaki | Adsorption | 0.386 mg/g | [24] |
| 19 | *Serratia marcescens* (NCIM2919) | Bacteria | Cd2+ | Chemicals | Ureolysis-induced calcium carbonate precipitation | 96% | [25] |
| 98% |
| *Enterobacter cloacae* EMB19 (MTCC10649) |

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| **Table 3:** **Genetically modified microorganisms for metal remediation through gene introduction/ alterations** | | | | | | | |
| **S. No** | **GM microorganism** | **Gene** | | **Metal** | **Output** | **Mechanism** | **Reference** |
| 1. | *Escherichia coli* | Four rice metallothionein (MT) isoforms as fusions with glutathione-S-transferase (GST) | OsMT1  OsMT2  OsMT3  OsMT4 | Hg | 20 nmol Hg2+/mg  13.7 nmol Hg2+/mg  10 nmol Hg2+/mg  7 nmol Hg2+/mg | Bioaccumulation | [26] |
| 2. | [*Pseudomonas*](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/pseudomonas)aeruginosa | CadR, cadmium (Cd)-specific binding protein | | Cd | 131.9 μmol/g of Cd (II) | Adsorption | [27] |
| 3. | *Chlamydomonas reinhardtii* | *Arabidopsis thaliana*  transporter (AtHMA4) | | Cd  Zn  Cd (1mM)  Zn (1mM) | Two-fold increase  (wild ~0.5 x 109 atom cell-1; HMA4CT4 ~ 1.4 x 109 atom cell-1)  Two-three-fold increase  (wild ~ 2 x 109 atom cell-1 ; HMA4-FL2 ~5.3 x 109 atom cell-1)  Wild ~2.2 ug mg-1; HMA4-CT1~2.5 ug mg-1  Wild ~3 ug mg-1; HMA4-CT1~4.3 ug mg-1 | Accumulation  Immobilization | [28] |
| 4. | *Deinococcus radiodurans* | *flr-2*fluorine-resistant gene | | U | 90% of U(VI) was removed | Biosorption and bioreduction | [29] |
| 5. | [*Pichia*](https://www.sciencedirect.com/topics/pharmacology-toxicology-and-pharmaceutical-science/pichia)pastoris | Overexpressing  [cytochrome b5 reductase](https://www.sciencedirect.com/topics/medicine-and-dentistry/cytochrome-b5-reductase) enzyme | | Ag  Se | 163.90 mg/g  63.71 mg/g | Biosorption | [30] |
| 6. | *Escherichia coli* Jm109  *E. coli* MT2A | human metallothioneins MT2A and MT3 | | Cr(VI) | 17 mg/g | Adsorption | [31] |
| 22 mg/g |  |
| 7. | *Chlamydomonas reinhardtii* | *acr*3 gene from *Pteris vittata* | | As | 1.5 to 3 times more removal than the wild-type strain  (wild ~30ug/L; ACR3 ~110ug/L at 0.5 mg/L arsenate) | Accumulation | [32] |



Supplementary Figure 1. Solid waste generation and their dumping leading to metal accumulation and the after-effects of metals on the environment and living organisms



Supplementary Figure 2. Graphical representation of bioremediation papers (as of Aug 15, 2021) for the last two decades using the keyword: Bioremediation (Source PubMed)

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