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# CHARACTERIZATION AND RESOURCE RECOVERY OF SEWAGE SLUDGE: A SUSTAINABLE WASTE MANAGEMENT APPROACH

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***Introduction***

Municipal sewage sludge, a by-product of wastewater treatment, contains a mixture of organic and inorganic materials, microorganisms, and various pollutants. The increasing generation of sludge, particularly from industrial sources, necessitates efficient management strategies to mitigate environmental impacts and support sustainable development. The transition to a circular economy framework promotes the valorisation of waste materials, including sewage sludge, through recovery of energy, nutrients, and reusable materials. This study investigates the physicochemical and energetic characteristics of sludge from a municipal wastewater treatment plant to assess its potential for recovery and reuse.

***Materials and methods***

Four sludge samples were collected from a municipal wastewater treatment facility. Were collected after the biological aerobic treatment stage. The samples were prepared by drying, sieving to a granulation below 1 mm, and separating or grinding oversized particles. Characterization techniques included: thermogravimetric analysis for moisture and dry matter content, elemental analysis (CHN analyzer) for carbon, hydrogen, and nitrogen content, calorimetry (IKA system) to determine calorific value, ICP-MS (Inductively Coupled Plasma Mass Spectrometry) for trace metal analysis. These analytical methods enabled a comprehensive assessment of the sludge's composition and energy potential.

***Results and conclusions***

The analytical results for the sludge samples, calculated on a dry matter (d.m.), are summarized in Table 1. The values show minimal variability among the samples, indicating a relatively uniform composition. The results demonstrate that sludge from industrial wastewater treatment has promising characteristics for energy and nutrient recovery. The consistency in composition, compliance with regulatory standards, and favourable calorific values support the implementation of circular economy principles in sludge management. Sewage sludge can be used as a soil amendment if it meets safety standards. Trace metal analysis showed concentrations within acceptable limits for agricultural use under Romanian regulation (Order 344/2004), including lead, cadmium, chromium and mercury.

**Table 1.** Analytical results of the studied sludge samples

| **Analyses** | **Unit of measurement** | **1-S** | **2-S** | **3-S** | **4-S** |
|---|---|---|---|---|---|
| Humidity | % | 76.2 | 78.9 | 79.0 | 77.6 |
| Carbon | % d.m. | 27.14 | 28.61 | 27.44 | 26.99 |
| Hydrogen | % d.m. | 3.41 | 4.14 | 4.29 | 4.52 |
| Nitrogen | % d.m. | 4.03 | 3.78 | 4.54 | 3.96 |
| Ash | % d.m. | 47.6 | 44.4 | 46.8 | 45.2 |
| Phosphor | % d.m. | 2.93 | 2.68 | 2.42 | 2.77 |
| Higher Calorific Value | MJ/kg d.m. | 11.42 | 11.88 | 12.08 | 11.95 |
| Loss On İgnition | % d.m. | 52.4 | 55.6 | 53.2 | 54.8 |
| Cadmium | mg/kg d.m. | 7.8 | 9.2 | 8.2 | 8.6 |
| Copper | mg/kg d.m. | 141 | 192 | 136 | 156 |
| Chromium | mg/kg d.m. | 82.1 | 85.4 | 76.9 | 77.1 |
| Mercury | mg/kg d.m. | <0.05 | <0.05 | <0.05 | <0.05 |
| Nickel | mg/kg d.m. | 126 | 135 | 156 | 148 |
| Lead | mg/kg d.m. | 133 | 141 | 112 | 159 |
| Zinc | mg/kg d.m. | 888 | 812 | 808 | 904 |

The analysed samples showed compliance with heavy metal limits, suggesting potential for reuse in agriculture. However, strict control is required due to the presence of trace elements and nitrogen compounds. Another viable method of valorisation is anaerobic digestion, which supports biogas (methane) production due to the high organic content of the sludge. Incineration or co-incineration in cement kilns is also feasible due to the calorific value of the sludge. Drying, preferably by solar methods, is necessary to increase combustion efficiency. Mechanical dewatering can only achieve up to 23–35% dry matter, thus additional drying is required. Overall, this research highlights the importance of integrated sludge management strategies that prioritize recovery over disposal. Advancing sludge reuse practices through improved technologies and regulatory support can contribute significantly to environmental sustainability. Future research should focus on optimizing recovery technologies and exploring innovative uses for by-products.