

STUDY OF THE POTENTIAL USE OF WASTE GENERATED AT THE WASTEWATER TREATMENT PLANT IN THE AGRICULTURAL SECTOR

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Abstract: In present time, there is no legal regulatory national document related to sludge management in Georgia, and the sludge removed from the treatment plant throughout the country is stored in the Wastewater Treatment Plants (WWTP) area after proper treatment (dewatering, drying). The purpose of our research was studying the limited and nutrients elements in the sludge generated at the WWTP and determine the optimal quantity/dosage for agriculture. Our studies have shown that the average values of seven heavy metals limited by the EU Directive do not exceed or only slightly exceed the established Limit Values and the annual maximum amount of sludge that can be used in the agricultural sector for 10 years is limited by the amount of zinc and is 68 092.06 kg/ha/year. Applying the specified amount of sludge to the soil primarily ensures its enrichment with the nutrient element - nitrogen.

Keywords: WWTP, Sludge, Pollutants, Nutrients, Soil

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Introduction

The Georgian government currently prioritizes the harmonization of waste management practices with European policy standards. Emphasis is placed on reducing waste generation and promoting its secondary utilization [1, 2]. This initiative aligns directly with the country's shift from a linear to a circular economy, necessitating the adoption of novel economic management frameworks. Integral to this transition is the incorporation of circular economy principles, which hinge significantly upon the efficient management of Georgia's crucial natural resources, particularly water.

On June 29, 2018, the Parliament of Georgia amended "The Law of Georgia on Water," underscoring the imperative to ensure

the efficacy of treatment facilities and equipment. This includes adherence to regulations governing the discharge of wastewater into the sewage system, as stipulated by technical regulations endorsed through government resolutions [3].

The efficiency of Wastewater Treatment Plants (WWTPs) encompasses both the treatment of wastewater to meet state normative levels using modern technologies and the proper management strategy for sludge generated by these plants [4-9].

Sludge generated at a Wastewater Treatment Plant (WWTP) is a complex conglomerate of living organisms within a non-living matrix, associated with metabolic and trophic processes. Produced in significant

quantities, it is classified as IV hazard class waste [10]. Comprising 70-90% organic substances and 10-30% inorganic substances, sewage sludge contains pollutants such as heavy metals and pathogens, alongside valuable organic and nutrient substances like nitrogen, phosphorus, and potassium. These attributes render it highly beneficial as a fertilizer or soil improver. Consequently, sludge from WWTPs should be regarded not merely as waste but as a valuable resource for agricultural applications [8].

Globally, the primary methods for recycling this type of waste include thermal incineration and co-incineration, pyrolysis, deposition (placement in designated areas), biological composting (aerobic fermentation), aerobic stabilization in air tanks, biogas production in methane tanks (anaerobic

fermentation), vermiculture (the artificial rearing or cultivation of earthworms), and utilization as fertilizer [11-18].

Unfortunately, Georgia currently lacks a comprehensive regulatory and legal framework for sludge management. Consequently, there is no national action plan or strategy for managing sludge from treatment plants, which ideally should be based on scientific evaluation. At present, such measures remain unimplemented.

The objective of our research is to explore the feasibility of utilizing waste (sludge) generated from treating agricultural, commercial, household, and street runoff wastewater (entering the sewage system) at water treatment plants. This exploration considers the unique economic and social aspects of Georgia, with a particular focus on the agricultural sector.

Experimental Part

Currently, Georgia hosts several urban wastewater treatment plants (WWTPs), including facilities in Gardabani (serving Tbilisi, Rustavi, Mtskheta, and Gardabani), Adlia (serving Batumi municipality), Sachkhere (private), Telavi, Ureki, Zugdidi, Anaklia, and several others under construction. Numerous WWTPs have also been designed. In the context of circular economy principles, sustainable development, environmental conservation, and public health protection, it is imperative to establish a rational management system for the tons of waste (sludge) generated at these facilities.

One of the significant sources of sludge in our country is the Gardabani WWTP, which has been selected as the focal point for scientific analysis aimed at devising a rational management strategy for WWTP waste (sludge). This study involves assessing the potential utilization of sludge in the agricultural sector, identifying beneficial (nutrient) and harmful components for agricultural use, and establishing safe and rational utilization limits. To achieve these objectives, the following tasks have been outlined:

1. Conducting research on the physical-chemical parameters of sludge generated at WWTPs;

2. Performing a quantitative study of harmful (limited) and nutrient elements relevant to the agrarian sector based on the data obtained from the research;
3. Determining the optimal (harmless/beneficial) quantity/dosage of sludge application in the agrarian sector.

To complete these tasks:

- Within one year (2023), the content of limited [19] and nutrient elements was determined in samples of dry sludge obtained by gravity thickening at the Gardabani WWTP from 2007 to 2023 (**Table 1**);
- A loyal strategy for the safe utilization of sludge for soil fertility and plant nutrition was developed, including the calculation of the required amount of sludge based on the limit values (Maximum Permissible Concentrations, MPC) of limited elements and amounts of nutrients.

This comprehensive approach aims to promote sustainable sludge management practices that benefit the agricultural sector while ensuring environmental and public health protection.

Table 1. List of limited and nutrient elements investigated within the framework of the study in the sludge generated at Gardabani WWTP

Metals	Nutrients
• Cadmium (Cd) • Copper (Cu) • Lead (Pb) • Zinc (Z) • Nickel (Ni) • Chromium_{total} (Cr_{total}) • Mercury (Hg) • Arsenic (As)	• Nitrogen_{total} (N_{total}) • Phosphorus (P) • Potassium (K)

Three types of dried sludge samples were taken for analysis from the years 2007, 2022, and 2023.

To determine the concentration of limited elements in the sludge, particularly heavy metals, the samples were processed using the Microwave Digestion System MDS-6G.

The total concentrations of Cd, Pb, As,

Zn, Cu, Ni, and Cr in the treated sludge samples were analyzed using a Microwave Plasma Atomic Emission Spectrometer (MP-AES). The concentration of Hg was determined using an Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) [20, 21]. The experimental data are presented in Table 2.

Table 2. Content of heavy metals in sludge generated at Gardabani WWTP

№	Indicators	mg/kg							
		As	Cd	Cu	Pb	Zn	Ni	Cr	Hg
1	Sludge sample (2007)	3.50	-	181.00	66.00	382.60	8.60	48.00	0.20
2	Sludge sample (2022)	3.30	0.70	157.00	40.60	470.00	23.60	122.90	0.20
3	Sludge sample (2023)	9.59	1.15	143.70	32.15	469.15	13.83	98.89	0.60
<u>Average</u>		5.46	0.93	160.57	46.25	440.58	15.34	89.93	0.33
Clark [22]		1.70	0.13	47.00	16.00	83.00	58.00	83.00	0.08
Ratio: Average heavy-metal /Clark		3.21	7.12	3.42	2.89	5.30	0.26	1.08	4.13
Limit values of concentration of heavy metals in soil (mg/kg of dry matter in a representative sample, as defined in Annex II C, of soil with a pH of 6 to 7) [19]		-	1-3	50-140	50-300	150-300	30-75	-	1-1.5
Limit values for heavy-metal concentrations in sludge for use in agriculture (mg/kg of dry matter) [19]		-	20-40	1000-1750	750-1200	2500-4000	300-400	500	16-25
Limit values of heavy-metal concentrations that can be added annually to agricultural soil based on a 10-year average (kg/ha/year) [19]		-	0.15	12	15	30	3	15	0.1

The following methods were used to determine nutrients in sludge samples:

- Potassium concentration was determined using the Microwave Plasma

Atomic Emission Spectrometry (MP-AES) method after sample pretreatment [20].

- Total nitrogen content was analyzed using the modified Kjeldahl method [23].

• Total phosphorus content was measured using the spectrophotometric method HACH DR 1900 (LCK 350), following sample pretreatment [24].

The results of nutrients analysis in sludge samples are given in Table 3.

Table 3. Nutrients content of sludge generated at Gardbani WWTP

№	Indicators	P	P ₂ O ₅	N _{total}	K
		g/kg			
1	Sludge sample (2007)	0.11	0.25	3.80	0.32
2	Sludge sample (2022)	0.76	1.74	12.90	0.85
3	Sludge sample (2023)	0.86	1.97	11.20	0.83
Average		0.58	1.32	9.30	0.67

Within the research framework, the macronutrients composition of the analytical sludge samples were determined after sample pretreatment. This included the analysis of chlorides (Cl⁻), soluble sulphates (SO₄²⁻),

fluorides (F⁻), sodium (Na), calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), and aluminum (Al) content [20, 23-25] (Table 4).

Table 4. Content of some macronutrients in the sludge generated at Gardbani WWTP

№	Indicators	g/kg								
		F ⁻	Cl ⁻	SO ₄ ²⁻	Na	Ca	Mg	Fe	Mn	Al
1	Sludge sample (2007)	0.004	0.14	2.75	0.53	2.70	0.30	22.92	0.47	12.15
2	Sludge sample (2022)	0.003	0.28	2.21	0.72	1.30	0.36	21.98	1.18	16.96
3	Sludge sample (2023)	0.003	2.13	2.01	0.59	3.00	1.80	15.13	0.49	15.54
Clark [22]		-	-	-	25.00	29.6	18.70	38.0	1.0	80.50
MPC in soil [26]		0.01	0.36	0.16	-	-	-	-	1.5	-

Results and discussion

It should be noted that the contents of pollutants and useful components found in the analytical sludge vary, depending on both the quantity and composition of the water entering the WWTP from the sewage system (which has gradually expanded in recent years due to an increase in the number of connected subscribers), and the management practices of the WWTP (up until 2019, only mechanical treatment was conducted at the research site). The average concentrations of heavy metals obtained from experimental data in the sludge were compared with the corresponding values from Clarke [22] (Table 2). It was determined that the concentrations of Cu, As, Pb, Zn, and

Hg in the sludges exceed those of Clarke by approximately 3.0-5.0 times, while the Ni and Cr content is close to Clarke's values. However, the concentration of Cd is approximately 7 times higher than the corresponding Clarke value. When comparing the results of the study of sludge samples generated at Gardabani WWTP with the corresponding limited values of concentration of heavy metals in soil, outlined in "Environmental protection, particularly soil protection during the use of sewage sludge in agriculture 86/278/EEC" [19], it was observed that the average concentration of heavy metals in the investigated sludge samples does not exceed the respective MPC for

soil, except for Zn and Cu. It is noteworthy that the concentrations of Cd, Ni, Hg, and Pb fall below the limit values (Table 2). To process the data obtained from the research by international standards and determine the optimal (harmless/beneficial) amount/dosage of sludge for use in the agrarian sector, we also referenced the Council Directive, which outlines requirements for soil protection when using sludge from WWTP for agricultural purposes [19]. The limits established in the directive were applied in our research, specifically: the Limit values/ MPC of heavy metals in soil; Limit values/MPC of heavy metal concentrations in sludge for use in soils intended for agriculture; Limit values/MPC of heavy metals that can be annually used on agricultural soil, averaged over 10 years (Table 5). It's important to note that the mentioned EU directive on sewage sludge addresses both the utilization and regulation/restriction of sewage sludge in agriculture, aiming to prevent harmful effects on soils, plants, animals, humans, as well as negative impacts on surface and underground waters. Furthermore, the document establishes limits for the concentration of seven heavy metals in sewage sludge intended for agricultural use (Cd, Cu, Ni, Pb, Zn, Hg, Cr)

and prohibits the use of sludge that would cause the concentration of these heavy metals in the soil to exceed specified limits.

Table 5 presents: (1) The average content of limited elements in the study sludge (2007-2023), measured in mg per kg; (2) The limit amount of each limited element in kg per hectare of soil for one year; (3) Using a simple equation, it is possible to calculate the maximum amount of sludge per hectare of soil (for each element) in kg per year over a 10-year period. For example, the annual loading rate of Cd is 0.15 kg/ha/year, and the average concentration of Cd in sludge is 0.93 mg/kg (equivalent to 0.93×10^{-6} kg Cd in one kg of sludge). Thus, the maximum amount of sludge per hectare of soil per year can be calculated as follows: Maximum sludge amount = Annual loading rate of Cd / (average concentration of Cd in sludge) = $0.15 / (0.93 \times 10^{-6}) = 161290.32$ kg sludge/ha/year. This result indicates that 161 tons of sludge can be used per hectare of soil. Similarly, by applying the same calculations, it is found that the minimum amount of sludge can be used in the case of Zn (68092.06 kg) since its content exceeds the limits compared to other metals.

Table 5. Annual maximum amount of sludge according to metal limits, which can be used in one ha of soil in the agricultural sector for 10 years, kg/ha/year

№	Indicators	Cd	Cu	Pb	Zn	Ni	Cr	Hg
1	Sludge (average 2007-2023), mg/kg	0.93	160.57	46.25	440.58	15.34	89.93	0.33
2	MPC, kg/ha/year	0.15	12	15	30	3	-	0.10
3	Maximum amount of sludge that can be added annually to agricultural soil based on a 10-year average, kg/ha/year	161290.32	74733.76	324324.32	<u>68092.06</u>	195567.14	,	303030.30

As mentioned previously, one of the significant objectives of the research was to assess the utility of sludge in terms of its nutrient content beneficial for the agricultural sector (Table 3). Considering the data provided in Table 5, which

indicates that the annual maximum amount of sludge usable in the agricultural sector for 10 years is constrained by the quantity of zinc, the utility of sludge was computed for 68092.06 kg of sludge (Table 6).

Table 6. Nutrient content of research sludge (kg/ha/year), which can be used in one ha of soil in the agrarian sector for 10 years

Indicators	P	P ₂₀₅	N _{total}	K
The average content of nutrients in research	0.58	1.32	9.30	0.67

sludge (2007-2023), g/kg				
68 092.06 kg of sludge per one ha of soil nutrient content in sludge per year, kg/ha/year	39.49	89.88	633.26	45.62

As a result of the research of the sludge generated in the Gardabani WWTP in different years (2007-2023), it was determined:

1. In accordance with the European Union Directive, the average contents of seven heavy metals (Cd, Pb, Zn, Cu, Ni, Cr, and Hg) in sludge either do not exceed or slightly exceed the established limit values/MPC (Table 2);

2. The content of some macronutrient investigated in the research sludge in general does not exceed the Limit values/MPC [22, 26] (Table 4);

3. The maximum amount of sludge that can be added annually to agricultural soil based

on a 10-year average is restricted by the quantity of Zn, as its concentration in the sludge surpasses the limit values/MPC for soil (Table 2 and Table 5);

4. The quantities of nutrients (N, P, K) according the maximum sludge amount per year primarily enriches it with nitrogen - 633.26 kg/ha/year (Table 3 and Table 6).

Based on the results obtained, it can be concluded that the dry sludge generated at the Gardabani WWTP can indeed serve as a beneficial agricultural supplement, with the determined limit of studied sludge is 68 092.06 kg/ha/year.

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