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Study on the Composition and Environmental Impact of Sewage Sludge

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ABSTRACT

The article examinee the characteristics of sewage sludge and its impact on the environment. The description of technical installations, sludge sites in the municipal wastewater treatment systems, which are sources of unfavorable sanitary and epidemiological condition of the studied territory, was presented. A detailed analysis of the structure, composition and morphology of sludge sediment was given. It was found that the sludge presents a loose, rough heterogeneous porous structure represented by the presence of a fibrous substrate with amorphous scaly-crystalline inclusions. During laboratory analyses of the composition of the dry residue, the presence of such types of heavy metals as chromium, manganese, nickel, copper, zinc, lead, cobalt, molybdenum, cadmium was revealed. The excess of permissible concentrations of various elements was observed: chromium more than 7.1 at MPC – 6.0 by 1.18 times; copper more than 3.3 at MPC – 3.0 by 1.1 times; zinc more than 27.3 at MPC – 23.0 by 1.18 times; lead more than 34.3 at MPC – 32.0 by 1.07 times; cobalt more than 6.4 at MPC – 5.0 by 1.28 times; molybdenum more than 6.9 at MPC – 5.0 by 1.3 times. Soil analysis revealed a pH of 7.1, which is neutral, may be optimal for plants; the concentration of calcium, iron and chromium does not exceed the established maximum permissible values. When analyzing the air environment of the territory of the treatment facilities, the presence of gaseous pollutants, such as methane, ammonia, nitrogen dioxide, hydrogen sulfide, carbon monoxide, was established. It has been established that anthropogenic sludge landfills are the sources that create a technogenic load on the atmospheric air, polluting it with methane, since the concentration of methane exceeds the MPC by more than 3 times.

Keywords: sludge, sewage treatment plants, wastewater, mapping.

INTRODUCTION

As a result of the vital activity of mankind, that is, the satisfaction of the daily needs of people, application of various technologies in different sectors of the national economy and agricultural work generates a large amount of waste from sewage and waste water.The sludge-forming sediment contains a number of substances with carcinogenic, toxigenic and embryotoxic properties [Sverguzova et al., 2015; Habagil et al., 2020; Mamy et al., 2020; Jabłońska-Trypuć, 2021; Korotaeva and Pashkevich, 2021; Lobacheva, 2021]. It contains both pathogenic microorganisms and a number of toxic compounds in the form of heavy metals, pesticides, nitrosamines, phenols and esters. It is known that the presence of harmful substances, depending on the concentration released by sludge-forming sediments, can exceed the standards of maximum permissible concentrations, with the release of an unpleasant gaseous foul-smelling odor [Pochwat et al., 2019; Letuyev et al., 2020; Iakovleva et al., 2021].

Treatment and reuse of solid waste and waste water polluting the environment, neutralization and reuse of urban wastewater (sewage) are urgent issues of our time in every country in the world.

The relevance of the work is aimed at the study of the territory of sewer systems, pollution of the gas-air environment, soil, the presence of pathogenic microorganisms, unfavorable sanitary and epidemiological condition [Aigars et al., 2017; Tian and Trzcinski, 2017; Pashkevich et al., 2020].

The purpose of the research was to study the composition of silt sediments as well as determine the elementary composition of the gas-air environment and soil to identify the impact on the environment.

The treatment facilities of Aktau are located in the immediate vicinity of the Caspian Sea coast 200 m, as well as from the Primorsky residential area 100 m, posing a threat to public health. The map-scheme of Aktau wastewater treatment plants wastewater treatment plants-1 is shown in Figure 1 [Naraev et al., 2020; Serikbaev et al., 2021; Kolesnikov et al., 2022a].

The total capacity of the treatment facilities currently amounts to 72 thousand m^3/day of wastewater that has undergone mechanical and biological treatment, and 42 thousand m^3/day of water (out of the total volume) are undergoing additional post-treatment [Nazarbek et al., 2021].

The plots of land used for sludge storage sites for sludge-forming sediment are often overcrowded, and unable to cope with the endless flow of waste in the form of precipitation. Harmful gases, dangerous bacteria, viruses, and toxic chemical compounds contained in high concentrations on the territory of sludge cart sites contribute to the emergence of certain threats and pollution to the environment and the city's population. In addition, as a result of fermentation, various gaseous substances entering the atmosphere under natural conditions can be released, which also affects the quality of atmospheric air and the health of the population [Vasilyeva et al., 2021a].

One of the urgent problems is the preservation of soils, since its contamination with any dangerous compounds, along the food chain, can enter the human body at any time [Filin et al., 2020; Kolesnikov, 2022b; Ulzhalgas, 2022].

Due to the annual increase in the population of the Mangystau region, the volume of waste generated, including excess activated sludge of urban wastewater, is also increasing. The resulting secondary sediments are divided into the following main categories: organic sediments of mineral structure and activated sludge [Efremova, 2012]. Before dehydration, organic sludge leads to normal fermentation or stabilization, as well as thermosetting effects. The technological scheme of preparation, processing and subsequent dewatering of organic sediments and activated sludge usually includes the following stages: preliminary pressing, dehydration, thermal drying (burning). To reduce the moisture content of the sludge, including active sludge it is pressed [Sizyakova, 2019a].

In Kazakhstan with a warm climate and hot summers, natural drying can be successfully applied for their dehydration, which is currently used at wastewater treatment plants (WTP) in Aktau (Fig. 2).

The sludge stored on silt sites is infected with dangerous bacteria that can cause various forms of infectious diseases, contains a large number of helminth eggs, heavy metal compounds of various

Figure 1. Map-scheme of treatment facilities WTP-1 in Aktau

Figure 2. Photo of the general view of the sludge platform

shapes. The exploitation of silt maps leads to the loss of valuable lands, soil pollution, the spread of unpleasant odors, the accumulation of heavy metal salts, as well as the spread of negative microbiological and gas background, which negatively affects the environment and human health [Kolesnikov et al., 2017].

When entering treatment plant, wastewater contains mineral pollution of various composition and content: clay particles, coarse sand, fatty oils, heavy metal ions; organic nature: oily sediments, hair, household solid waste, feces; bacterial nature: algae, microorganisms, yeast and moldy fungi; various suspended substances. Wastewater, passing through several stages of purification, forms a sludge, which cannot be treated, except for dehydration and drying under a natural condition [Bondarenko et al., 2017].

The difficulty in this case is the need for a long time for natural drying and the allocation of huge areas for silt maps. The presence of a large volume of excess sludge leads to the spread of an unfavorable gas-air background, contamination of groundwater and soil with toxic substances contained in the sediment [Kolesnikov et al., 2021].

MATERIALS AND METHODS

The structure and morphology of the sludge of municipal sewage was studied by scanning electron microscopy on the JSM-6490LV apparatus (Jeol Company, Japan). Operating mode of the microscope: accelerating voltage U = 10 and 20 kV; resolution in high vacuum mode – 3 nm, in low vacuum mode – 4 nm; magnification range – from ×40 to ×20000; contrast – topographic with secondary scattered electrons, as well as composite, topographic and shadow with reflected electrons. Sediment samples were deposited on a special substrate made of double-sided carbon tape. The remains of the samples that were not glued to the substrate were removed with a jet of air. Then the samples were placed in a microscope column [Zhakipbaev et al., 2021].

The composition of sewage sludge was carried out on the Fluorat - 02 liquid analyzer, M01-26-2001, STB ISO 11885-2011 (manufactured by Lumex- Marketing LLC, Russian Federation, St. Petersburg). “Fluorat-02” fluorescent-photometric liquid analyzers are designed to measure the content of various components in liquid media by photometric and luminescent methods [Zheng Y. et al., 2022].

Sampling was carried out in accordance with the methodology presented in the “Manual for the Control of Atmospheric Pollution” – atmospheric air samples were taken at each point and measurements were carried out on the GANK-4 gas analyzer (AR) (manufactured by NPO Pribor Gank, Russian Federation, Moscow) at a height of 2 m from the earth’s surface. When measuring concentrations, the analyzed air enters through the inlet fitting to the sensor or chemical cassette. After a time of no more than 20 seconds (when measured by a sensor), or a time of no more than 30 seconds (when measured by a chemical cassette), the signal enters the computing device, which converts it and outputs it to the device screen as the values of the current ($C_{curr.}$) and average ($C_{avg.}$) concentrations in mg/m^3 [Torunova, 2019].

Analyses of soil samples of the studied territory were carried out on the basis of State

Standard 26426-85-Soils – methods for determining the sulfate ion in an aqueous extract. The essence of the method consists in precipitation of the sulfate ion with a solution of barium chloride and weighing of the calcined residue [Gebreeyessus and Jenicek, 2016]. To prevent precipitation of carbonate, barium phosphate and other compounds, the analyzed sample is acidified with hydrochloric acid. The essence of the method consists in sequential complexometric titration in one sample of calcium ions at pH 12.5–13 and magnesium ions at pH about 10 using dark blue acid chromium as a metal indicator on the basis of State Standard 27395-87-Soils – method of determination of mobile compounds of ferrous and trivalent iron by Verigina-Arinushkina. The essence of the method consists in the extraction of mobile compounds of di- and trivalent iron from the soil with a solution of sulfuric acid with ($1/2H_2S0_4$) = 0.1 mol /dm^3 at a soil: solution ratio of 1:10 for mineral soils and 1: 50 for peat soils, stirring time of 5 minutes, followed by determination in extracts of ferrous iron photometrically with α,α-dipyridyl or o-phenanthroline and amounts of di- and trivalent iron by photometric or atomic absorption method on the basis of State Standard 26213-91-Soils – methods for determining organic matter. The method is based on the oxidation of organic matter with a solution of potassium bicarbonate in sulfuric acid and the subsequent determination of trivalent chromium equivalent to the content of organic matter on a photoelectrocolorimeter [Nasyrov, 2015; Pittmann and Steinmetz, 2017; Jeske and Gallert, 2021; Conejo-Saucedo et al., 2021; Moestedt et al., 2020; Zheng G. et al., 2022].

RESULTS AND DISCUSSION

In addition to the raw sludge, the sludge from primary settling wastewater for household purposes, as well as overactive sludge from the municipal wastewater, is also disposed of at silt sites. Today, in Aktau, the recycling of spent activated sludge is represented by sludge maps-sites. Designed land plots for sludge platforms, surrounded by a shaft of earth around the perimeter. Silt-feeding troughs designed for the discharge of silt sediments and representing the basis of the entire structure are carried out along the shafts [Jover-Smet et al., 2017]. The raw sludge-forming sediment coming from special settling tanks is able to accumulate in large volumes on sludge sites and during the drying process is able to lose moisture in the amount of 24–31%, followed by the acquisition of an appearance and structure similar to wet earth. After the dried sludge is removed with the help of special transport and used as a filler to the soil for landscaping urban green spaces [Chadaeva and Zabolotskikh, 2014].

Thus, in order to eliminate the negative impact of sewage sludge on the environment and soil fertility in the study area, a set of measures aimed at restoring the lost natural soil fertility is required [Nájera et al., 2017].

The object of laboratory experiments is sewage sludge, its composition, structure and morphology (Fig. 3). Sewage sludge after its treatment and dehydration was taken from the State Enterprise "Kaspiy zhylu, su arnasy" in Aktau, Mangystau region, Kazakhstan [Tan et al., 2019].

Analysis of the sediment revealed a loose, rough, heterogeneous porous structure, represented

Figure 3. Sludge sediment under a microscope

by amorphous flakes, crystalline inclusions and the presence of a fibrous substrate. By measuring the linear dimensions of the microrelief of the sediment surface, it was found that the sludge substrate consists of many particles from 0.1 to 500 microns, some of them are aggregated. The developed porosity, proves the presence of moisture-absorbing and moisture-retaining properties in the sewage sludge [Vasilyeva et al., 2021b].

The composition of the sludge of treatment plants varies within large limits (Table 1), and determination based on the method of measuring the mass concentrations of heavy metals in samples of excess sludge, provided for the use of a fluorimetric method using a Fluorat - 02 liquid analyzer, M01-26-2001, STB ISO 11885-2011 (manufactured by Lumex-Marketing LLC, Russian Federation, St. Petersburg) [Chukaeva et al., 2022].

The results of the analysis of the dry matter of the sewage sludge provide for the presence of heavy metals in moderate concentrations. There is a slight excess of some elements: chromium more than 7.1 at MPC – 6.0 by 1.18 times; copper more than 3.3 at MPC – 3.0 by 1.1 times; zinc more than 27.3 at MPC – 23.0 by 1.18 times; lead more than 34.3 at MPC – 32.0 by 1.07 times; cobalt more than 6.4 at MPC -5.0 by 1.28 times; molybdenum more than 6.9 at MPC – 5.0 by 1.3 times.

When sampling the gas-air environment of the territory of sewer systems, the following indicators of pollutants were identified, see Table 2.

The results of the analysis of the gas-air environment of the territory of sewer systems indicate an excess of methane by more than 3 times, according to other indicators, the quality of atmospheric air corresponds to acceptable indicators [Lutskiy and Ignativich, 2021].

Given that the annual value of total solar radiation exceeds 125 kcal/cm^2, up to 65% of this amount fall on direct solar radiation. The greatest amount of solar heat comes in the summer months. The arrival of significant amounts of solar radiation is ensured by a long duration of sunshine (more than 2,600 hours per year) and the frequent recurrence of clear days. The average annual air temperature ranges from 9.5°C to 11°C. The warm period (with an average daily air temperature above 0°C) lasts on average 280 days [Savard et al., 2021].

Table 1. Composition of sediment dry matter (June-December 2021)

Heavy metals	Sewer systems – trial sites						
	June – December						
	TS-1 July	TS-2 August	TS-3 Septem-ber	TS-4 October	TS-5 November	TS-6 December	MPC, mg/kg including background (clark)
Cr	6.8	7.1	6.8	6.05	6.07	6.04	6.0
Mn	257.1	357.8	324.7	267.9	268.4	251.3	1500
Ni	3.0	3.5	3.2	3.1	3.0	2.7	4.0
Cu	3.2	3.3	3.2	3.1	3.0	3.1	3.0
Zn	26.3	26.4	27.3	26.8	25.9	25.4	23.0
Pb	33.9	34.3	33.4	33.7	32.6	32.2	32.0
Co	5.7	6.4	6.2	5.9	5.4	5.1	5.0
Mo	6.4	6.9	6.6	6.3	6.1	6.1	5.0
Cd	1.7	2.2	1.9	1.8	1.8	1.7	2.0

Table 2. Results of atmospheric air sampling on the territory of STP-1 (June-December 2021)

Gaseous substances	Sewer systems – trial sites						
	July – December						
	TS-1 July	TS-2 August	TS-3 September	TS-4 October	TS-5 November	TS-6 December	MPC, mg/m^3
CH_4	151	168	143	149	135	147	50
NH_3	0.00678	0.00789	0.00698	0.00679	0.00655	0.0681	0.2
NO_2	0.00122	0.00145	0.00138	0.00131	0.00142	0.00134	0.2
H_2S	0.00118	0.00124	0.00136	0.00127	0.00137	0.00129	0.008
CO	0.426	0.458	0.463	0.521	0.487	0.429	5

Recently, an increase in annual air temperature and seasonally, an increase in precipitation in winter and a decrease in precipitation in the spring months, a high abnormality of precipitation when rains are combined with drought, have their negative impact on the soil condition, that is, heavy rains in the spring months can not moisten the soil well, since water cannot evenly to be absorbed, and on days when the air temperature rises, there is a rapid evaporation of soil water [Ekaterina and Lutskiy, 2019].

Proceeding from the above, as well as taking into account and evaluating the specifics of wastewater treatment technologies, collection, processing and reuse of formed sediments and in particular sludge, the possibility of reducing their harmful impact on the environment in this scientific article, based on scientific research of sludge deposits of wastewater of Aktau, shows the versatility of properties and the complexity of the chemical composition of this research object [Sizyakova, 2019b]**.**

The territory under consideration, according to the soil-geographical zoning of the USSR, belongs to the Aral-Caspian province of the desert zone of gray-brown soils of the desert-steppe and desert region of the subboreal belt. The soils of the site under consideration are characterized by a low content of humus substances and a small thickness of the humus horizon. These features are a consequence of the special climatic conditions of the territory [Siziakova and Ivanov, 2020].

For a more detailed study, soil sampling was carried out in accordance with State Standard 17.4.4.02 Nature Protection. Soils. Methods of sampling and preparation of samples for chemical, bacteriological, helminthological analysis from the territory of WTP-1 near silt maps. The analysis was carried out by the accredited "Accu Test" testing center. The results of the soil analysis are shown in Table 3. The results of the soil analysis indicate that pH 7.1 is neutral, may be optimal for plants; the concentration of calcium, iron and chromium does not exceed the established maximum permissible values [Boikov et al., 2021].

CONCLUSIONS

On the basis of the results obtained from the conducted studies, the following conclusions follow. Sludge platforms act as a technogenic source of atmospheric pollution with methane, there is an increase in the values of the maximum permissible concentration for methane by more than 3 times, with a maximum concentration of 50 mg/m^3. The average temperature regime in Aktau in the summer ranges from 37–44°C, thereby reducing the drying time and dehydration of sludge. In summer, due to the heating of semi-liquid sludge, the volume of release of gas-air pollutants increases.

Analysis of the sediment revealed a loose, rough, heterogeneous porous structure, represented by amorphous flakes, crystalline inclusions and the presence of a fibrous substrate. The content of heavy metals in the composition of the dry sediment indicates a slight excess of the established norms: chromium more than 7.1 at MPC – 6.0 by 1.18 times; copper more than 3.3 at MPC – 3.0 by 1.1 times; zinc more than 27.3 at MPC – 23.0 by 1.18 times; lead more than 34.3 at MPC – 32.0 by 1.07 times; cobalt more 6.4 at MPC -5.0 by 1.28 times; molybdenum more than 6.9 at MPC - 5.0 by 1.3 times. Soil analysis indicates that pH – 7.1 is neutral, may be optimal for plants; the concentration of calcium, iron and chromium do not exceed the established maximum permissible values. In order to eliminate the negative impact of sewage sludge on the environment and soil fertility in the study area, a set of measures aimed at restoring the lost natural soil fertility is required.

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Table 3. Results of soil analysis (June-December 2021)

Name of indicators mg/kg	Sewer systems – trial sites						MPC substance	ND designations for test methods
	July – December							
	TS-1	TS-2	TS-3	TS-4	TS-5	TS-6		
pH	7.2	7.2	7.1	7.2	7.2	7.1	neutral	State Standard 26426-85
Ca	0.06	0.08	0.07	0.07	0.08	0.08	–	State Standard26428-85
Fe	2.3	2.4	2.03	2.08	2.1	2.2	–	State Standard 27395-87
Cr	0.00868	0.00785	0.00845	0.00812	0.00875	0.00794	6.0	State Standard26213-91

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