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Article

Quality assessment of sludge from filter washings in swimming pool facilities

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Abstract: Swimming pools are examples of water-intensive facilities, where solutions for reducing economic and environmental costs are increasingly frequently searched. One of the solutions is the recovery of water from wastewater, including from washings obtained through the process of rinsing filter bed. The study objective was the qualitative and quantitative assessment of post-coagulation sludges, the main pollutant found in the washings. During the analyses, assessment of the sedimentation capabilities of the sludges was performed (gravitationally), particle size distribution was assessed (particle size distribution analyzer) and assessment of phytotoxicity with the use of plant indicators in short-term tests was performed (*Lemna minor*, *Lepidium sativum*, *Sinapis alba*, *Raphanus sativus*). The samples were collected from two independent circulations, which differed in terms of capacity and type of coagulant used. The tested post-coagulation sludges were characterized by high content of total suspended solids: in samples from Circulation 1 from 251 to 128 mg/l, in Circulation 2 from 489 to 228 mg/l. However, the sedimentation processes enabled significant separation of sludges. The hydrolyzed coagulant contributed to the improvement of sedimentation capabilities of sludges. Despite the fact that in many samples low sludge concentrations favored stimulation of plant growth, the post-coagulation sludges can constitute a hazard to plant growth, particularly in the long-term perspective.

Keywords: ecotoxicology; post-coagulation sludge; phytotoxicity; inhibition test; germination inhibition test; particle size distribution; pressure sand filter; circular economy; toxicity classification; gravitational properties of sludge

1. Introduction

Considering the increasing frequency and duration of heat waves in Europe and the local shortage of fresh water resources, more attention should be paid to the possibilities of recovering usable water from waste streams [1,2]. Possibilities of utilization of washings from porous beds rinsing constitute a problem analyzed in the literature, e.g. heat recovery and use for flushing toilets [3-5]. The interest in water recovery and washings reuse will increase in the near future due to the regulations of the European Parliament introduced in 2020 regarding the minimum quality requirements for reused wastewater [6]. At the same time, washings from swimming pool facilities, due to their quality, offer much greater possibilities of recovery than wastewater [3,7].

The efficiency of the filtration process has a significant impact on the quality of the water in the pool [8]. Water in a closed circuit is purified and disinfected continuously and its losses are supplemented with feed water, e.g. tap water. In the process of water filtration, a gradual bed collimation takes place, which consists in the fact that suspended solids, fibers and post-coagulation sediments attach to the grains. As a result, the space between them gradually fills up (bed porosity decreases) and the hydraulic resistance of the bed increases. In this process, rinsing water flows under pressure from the bottom upwards through the nozzles located at the bottom of the filter (in the direction opposite

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to normal filtration) [8-11]. Rinsing of pressure filters should last as long as the rinsing water (washings) is completely clear. According to the recommendations, it is necessary to use from 4 to 6 m^3 of water for each m^2 of filter bed for proper rinsing [12].

The operation of a swimming pool facility requires a significant demand for water for domestic and household purposes. Apart from rinsing the filters, water for technological purposes is used to replenish losses in the circulation. Monthly water loss in a single pool is about 10% of its capacity (for a swimming pool of average capacity of 576 m^3, it is over 57 m^3). The daily recommended fresh water intake is 30 dm^3 per swimmer [12]. However, in practice this consumption varies and depends on the load and size of the facility (from 28 to 86 dm^3/person) [13, 14]. In addition, water is consumed for the sanitary needs of the facility users and staff and for cleaning works within the building and adjacent green areas.

For example, daily water consumption in the facility with swimming pool, leisure pool and spa bath, in which water treatment circuits have a total capacity of 75.9 m^3/h, is 9.88 m^3/d (calculated based on the efficiency of the sample cycle). The volume of water consumed depends on the function and type of the pool, the method of technological solution, the efficiency of the equipment used, the attendance, the standard of equipment of the facility, the season of the year, the standard of living of the population and additional purposes [13,14].

The quality of the washings depends on many factors, including the length of the filtration cycle, the type and number of filters, the method of bed rinsing, the quality of supplementary water, the technology used, and the hydraulic conditions of the pool basin [3]. The washings are characterized by a large amount of suspended solids and residues of coagulants, added to the treated water before entering the filter bed [3,15]. The concentration of organic matter in the washings is mainly concentrated around particles larger than 45 μm [15]. A high proportion of 30 μm size fractions was also reported, as well as nanoparticles, approximately 955 nm in size [16].

Previous results of studies on evaluating the possibility of discharging washings into water or land show that it is necessary to apply sedimentation and dechlorination to reduce the most problematic physicochemical indicators [3,4,17]. The content of total suspended solids in the washings shows varied values ranging from 28 to 360 mg/dm^3 [3,17]. They are characterized by high precipitation, ranging from 81 to 96% relative to their total volume. For example, a two-hour sedimentation process reduces total suspended solids from 360 to 84 mg/dm^3 [17]. As a result of a 12-hour free chlorine disappearance process, the value of this parameter can be reduced by up to 80% [3,17]. Sedimentation also allows for partial reduction of COD [17].

Considering the significant share of sludge and suspended particles in the volume of washings, we should also analyze the potential possibilities of managing sludge from swimming pool washings - its volume share in the stream, its physicochemical properties, chemical stability and ecotoxicological risk. Because the management of waste sludge is an increasingly studied problem of the circular economy [18].

The aim of this study is a preliminary analysis of the physicochemical and ecotoxicological quality of gravity thickened sludge from washings collected in two pool water circuits.

2. Materials and Methods

2.1. Subject of the study

The subject of the study were samples of sludge from washings collected after rinsing of the filter beds operating in swimming pool facilities. The washings were collected in two municipal swimming pools once a week, in four independent samplings for each of the circuits.

In the swimming pool no. 1, the samples were taken from the common circuit of the swimming pool and the slow lane (located by the slide) - hereinafter referred to as circuit

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1 (Circuit 1, the characteristics of the objects can also be found in the Supplement). Water in this circuit is purified by a multilayer sand bed with a hydroanthracite layer. There are three similar beds with 1800 mm diameter and filtration area of 2.54 m^2 each. The rinsing process is carried out manually with compressed air and water. The volume of water used for rinsing in this cycle is 4.75 m^3/m^2 of bed. Each of the beds is rinsed every 24 hours, and the water is discharged into the municipal sewage system. The filtration process is accompanied by coagulation with aluminum sulfate (8.5%) and disinfection with sodium hypochlorite produced *in situ* by membrane electrolysis.

In the swimming pool No. 2, the samples were taken from the common circuit of the swimming pool, the recreation pool and the slow lane, further designated as circuit 2 (Circuit 2). Water in this circuit is purified on multilayer sand beds with a hydroanthracite layer, of various dimensions. In this circuit there are two filters with diameter of 1800 mm (area of each bed is 2.54 m^2), two filters with diameter of 2350 mm (area of each bed is 4.30 m^2) and a filter with diameter of 2000 mm (area of bed is 3.14 m^2). Rinsing process is carried out with compressed air and water. The volume of water used for rinsing is 4.09, 4.16 and 4.39 m^3/m^2 of bed (given according to the order mentioned earlier). The beds serving the swimming and recreational pools are rinsed every 24 hours, whereas the bed for the slow lane is rinsed every 48 hours. The filtration process is accompanied by coagulation with aluminum hydroxychloride (10%) and disinfection with stabilized sodium hypochlorite.

The samples were collected into 10-liter plastic canisters through drain channels during the rinsing process conducted after the facility was closed in the evening.

The sedimentation process in Imhoff funnels was carried out for 24 hours, the change of selected physicochemical parameters (described in subsection 2.2) was analyzed during this time. After 24 hours, the treated washings were decanted from the sludge. The sludge was collected for further analyses.

2.2. Characteristics of the sludge

During sedimentation of the sludge, the changes in the content of total suspended solids and the increase in the sludge settled by gravity in the Imhoff funnel were measured. The total suspended solids (TSS) content was determined by the method of filtration through glass fiber filters [19]. The TSS results and sediment volumes [mL] presented are the mean value of four independent replicates. The graphs show the value of the arithmetic mean together with the standard deviation.

Then, samples of gravity thickened sediments were analyzed with the use of a Mastersizer 3000 particle size distribution analyzer (Malvern) with Hydro EV (dip-in wet sample dispersion), in the range of 0.01 - 3500 μm. The presented results are the average of five measurements taken automatically by the device.

Photographs were taken with an optical microscope of the samples of the tested sediments. At the same time, the assessment of the sediment phytotoxicity was started.

2.3. Assessment of the phytotoxicity of sludge

The gravitationally compacted sludge were subjected to ecotoxicological analyzes. The influence of sludge in the samples was assessed for 10, 30, 50, 80, 100% of the hydrated sludge volume in deionized water. Control samples consisted of deionized water. The assessment of the changes of phytotoxicity of method based on the US EPA recommendations [20] using *L. minor* as the indicator organism. The assessment of matrices phytotoxicity was made based on the observation of either stimulation or inhibition of the growth in the number of fronds in a 7-day test (from day $t_1 = 0$ to day $t_2 = 7$). The average specific growth rate for a specific period is calculated as the logarithmic increase in the growth variables - frond numbers, using the formula below for each replicate of control and treatments:

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$$\mu_{i-j} = ((\ln(N_j) - \ln(N_i)/t) \quad (1)$$

where: μ_{i-j} - average specific growth rate from time i to j; N_i - measurement variable in the test or control vessel at time i; N_j - measurement variable in the test or control vessel at time j; t - time period from i to j.

Percent inhibition of growth rate (I_r) may then be calculated for each test concentration (treatment group) according to the following formula:

$$\%I_r = ((\mu_C - \mu_T)/\mu_C) \cdot 100 \quad (2)$$

where: I_r - percent inhibition in average specific growth rate, μ_C - mean value for μ in the control; μ_T - mean value for μ in the treatment group.

The plant growth inhibition (phytotoxicity) indicator and growth inhibition coefficient values were positive, while the growth stimulation was indicated by negative values. The phytotoxicity tests of the samples were performed in parallel with the physicochemical assessment. To describe the results of ecotoxicological analyzes, a unified concept of the toxic effect was used, denoted as E (%) [21]. Negative frond growth inhibition values mean stimulation of their growth. The samples are classified according to the magnitude of the toxic effect: I < 25% - non-toxic; I = 25.1 - 50% - low toxic; I = 50.1 - 75% toxic; I = 75.1 -100% - highly toxic [21].

All samples in Inhibition Test were carried out in triplicate, and the results were expressed as mean ± SD. The results presented graphically represent the mean value of all the independent trials performed.

2.4.1. *Germination Inhibition Test*

The assessment of the phytotoxicity of matrices using common radish (*Raphanus sativus*), watercress (*Lepidium sativum*) and white mustard (*Sinapis alba*) was made based on the Phytotoxkit® test method [22]. The 5 ml of test samples (10, 30, 50, 80, 100% of the hydrated sludge volume in deionized water) were poured on Petri dishes, and then 10 pieces of *R. sativus* and *S. alba* seeds were sown on each of the samples, the plates were placed in a laboratory incubator (Elkon) at a temperature of 25±0.5°C. The number of sprouted seeds and the length of the roots were read after 72 hours.

The presented results are the mean values of three performed repetitions. The phytotoxicity test included a test with fresh matrices as well as control. The examined effects of phytotoxicity included relative seed germination (RSG), plants relative root growth (RRG) and germination index (GI) [23]:

$$RSG(\%) = \frac{number\ of\ seeds\ germinated\ in\ test\ sample}{number\ of\ seeds\ germinated\ in\ control} \times 100 \quad (3)$$

$$RRG(\%) = \frac{mean\ root\ lenght\ in\ test\ sample}{mean\ root\ lenght\ in\ control} \times 100 \quad (4)$$

$$GI(\%) = \frac{RSG \times RRG}{100} \quad (5)$$

The toxicity classification is presented in Table 1 was used to interpret the Germination Index values [23, 24].

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Table 1. Toxicity classification based on the germination index GI [23,24].

Germination Index Value	Effect
GI ≥ 100	Growth stimulation
100 > GI ≥ 80	Non-toxicity
80 > GI ≥ 50	Moderate toxicity
50 > GI	High toxicity

All samples in Germination Test were carried out in triplicate, and the results were expressed as mean ± SD. Means and standard deviation were calculated using the MS Excel statistical package. The results presented graphically represent the mean value of all the independent trials performed.

3. Results

3.1. Characteristic of the sludge

Total suspended solids concentration in the tested samples was high, yet it differed significantly depending on the individual sampling. The washings collected from Circuit 1 had the TSS content ranging between 251 and 128 mg/L (Figure 1 (a) – (d)). And the highest value was recorded for Sample 1 (251.00 ± 23.48 mg/L), while the lowest for Sample 3 (128.00 ± 4.76 mg/L). Sludge from Circuit 1 was characterized by susceptibility to sedimentation. Within first 30 minutes the content of total suspended solids were reduced to 130.25 ± 26.65 mg/L and 92.25 ± 8.66 mg/L, respectively, for Sample 1 and 3 (Figure 1 (a) – (d)).

In this period, the increase of sludge on the bottom of Imhoff funnel was analyzed by reading the volume. First readings after 30 min of sedimentation were: 5.2 ± 0.7 mL; 4.7 ± 0.6 mL; 4.0 ± 0.2 mL and 3.8 ± 0.3 mL, respectively, for Samples 1; 2; 3; and 4 from Circuit 1 (Figure 1 (a) – (d)). With increasing sedimentation time the volume of the sludge first increased and then decreased, and the sludge settled on the bottom of the funnel, subject to concentration. After 24 hours of sedimentation the volume of the concentrated sludge in the samples was: 4.9 ± 0.7 mL; 3.8 ± 0.8 mL; 4.1 ± 0.5 mL and 3.7 ± 0.3 mL, respectively, for Samples 1; 2; 3 and 4 (Circuit 1) (Figure 1 (a) – (d)).

Prolongation of the sedimentation process to 24 hours aimed at the removal of the highest amount of sludge possible and obtaining values compliant with the legal regulations [25]. This makes it possible to discharge the supernatant liquid into the environment. The majority of the tested samples met those requirements. In Circuit 1 only for Sample 4, the required removal of total suspended solids below 35 mg/L or 90% reduction (reduction level was 76.40%) was not obtained. The total suspended solids concentration after a day of sedimentation was: 27.75 ± 7.41 mg/L; 33.25 ± 3.77 mg/L; 25.25 ± 4.99 mg/L and 38.75 ± 2.99 mg/L, respectively, for Samples 1; 2; 3 and 4 (Circuit 1) (Figure 1 (a) – (d)).

The analogous analysis was conducted for washing samples in Circuit 2. Washing samples from Circuit 2 were characterized by higher concentrations of total suspended solids. The TSS content ranged from 489 to 228 mg/L (Figure 1 (e) – (h)). And the highest value was recorded for Sample 1 (489.00 ± 15.34 mg/L), while the lowest for Sample 4 (228.00 ± 14.97 mg/L).

After 30 minutes of sedimentation the total suspended solids concentration was reduced to the following values: 247.50 ± 11.73 mg/L; 259.75 ± 25.79 mg/L; 142.50 ± 10.85 mg/L and 133.25 ± 7.09 mg/L, respectively for Samples 1; 2; 3 and 4 (Figure 2 (e) – (h)). On the other hand, the TSS values after 24 hours amounted to: 37.25 ± 6.65 mg/L; 35.00 ± 6.22 mg/L; 34.25 ± 8.66 mg/L and 35.25 ± 9.00 mg/L, respectively, for Samples 1; 2; 3 and 4.

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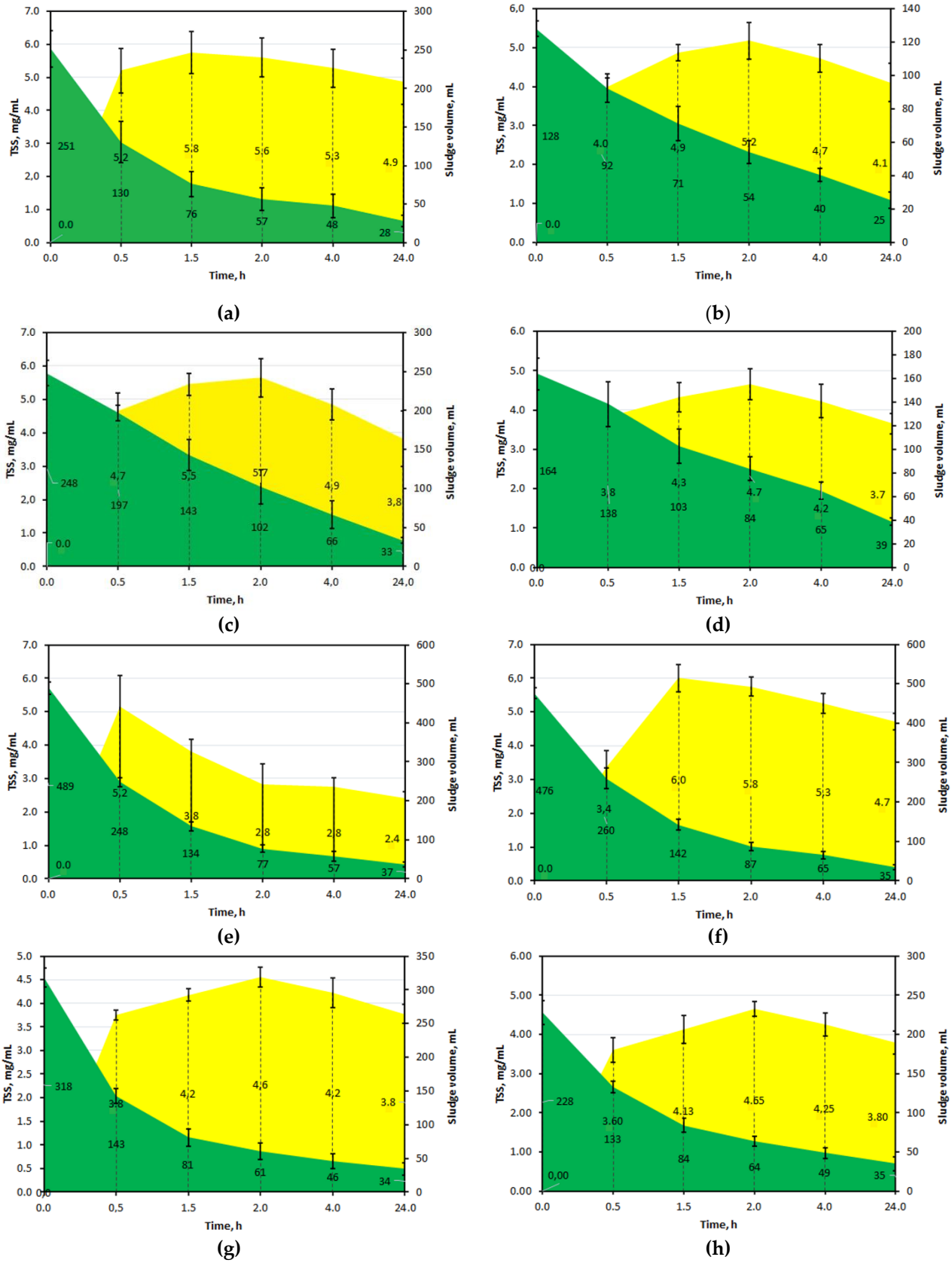

Figure 1. Analysis of the total suspended solids content and the volume increase of the sediment in the washings samples (Circuit number: Sample number): (**a**) Circuit 1: Sample 1; (**b**) Circuit 1: Sample 2; (**c**) Circuit 1: Sample 3; (**d**) Circuit 1: Sample 4; (**e**) Circuit 2: Sample 1; (**f**) Circuit 2: Sample 2; (**g**) Circuit 2: Sample 3; (**h**) Circuit 2: Sample 4.

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Despite the higher content of total suspended solids in samples from Circuit 2 as compared with Circuit 1, no significant increase in sludge volume could be observed. Mean volume of sludge in the samples after 30 minutes of sedimentation was: 5.2 ± 0.9 mL; 3.4 ± 0.5 mL; 3.8 ± 0.2 mL and 3.6 ± 0.32 mL, respectively for Samples 1; 2; 3; and 4. After 24 hours of sedimentation the volume of sludge in these samples was: 2.4 ± 0.2 mL; 4.7 ± 0.2 mL; 3.8 ± 0.2 mL and 3.8 ± 0.29 mL (Figure 2 (e) – (h)). It was also observed that Sample 1 Circuit 2 did not differ in terms of the course of the concentration process from other sludge samples analyzed.

The concentrated sludge was compared in terms of the percentage contribution of a specified particle size in the concentrated sample. Distribution analysis demonstrated heterogeneity of the tested sludge samples (Figure 2). However, all samples were characterized by the presence of particles with diameters ranging between 1.0 and 1000 μm, and the maximum % of volume did not exceed 8%. In Sample 1 Circuit 1 the highest percentage contribution characterized particles in the range between 10 μm and 100 μm (Figure 2(a)). In the case of the Sample 2 the range of particle size was greater, and close to 4% of particles ranged between 100 and 500 μm (Figure 2(b)). In Sample 3 the distinction between two particle size ranges was even clearer, with over 4 % contribution of volume concerned their sizes between 40 and 50 μm and from 110 to 130 μm (Figure 2(c)). In Sample 4 Circuit 1 one particle size range was distinguished. Over 5% of volume contribution characterized samples from 10 to 80 μm (Figure 2(d)). The main methodological problem at this stage was the concentration of the sludge and the selection of measurement parameters so that the delicate flocs did not disintegrate (which can make reliable measurement difficult).

Samples collected from Circuit 2 demonstrated similar size ranges to the samples from Circuit 1 (Figure 2 (e) – (h)). Sample 1 had the 10 ÷ 50 μm range, characterized by close to 6% contribution in the sludge, and about 3% contribution characterized samples with size close to 110 μm (Figure 2 (e)). Sample 2 exhibited over 6% contribution in the range between 20 to 50 μm (Figure 2 (f)). Sample 3 was characterized by over 2% contribution in the range 60 ÷ 600 μm, and the particles in the range from 10 to 30 μm contributed to over 4% of the sample (Figure 2 (g)). Sample 4 was characterized by the highest percentage share of samples in the range from 10 to 50 μm (Figure 2 (h)).

Due to the possibility of diverse contaminants occurring in swimming pool washings, as well as in their sludge. The selected samples were subject to a microscopic observation. Apart from the sludge particles with different size, typically forming aggregates, the samples were observed to feature: numerous fibers and fine fragments (below 10 mm) from swimwear (Figure 3 (a), (b), (c), (d)). As well as sand and hydroanthracite grains, which were flushed from the medium during the backflushing process (Figure 2 (a), (c)). Moreover, the sludge was observed to have small cilliates feeding on the flocculi, i.a. of the genus *Colpidium* and *Paramecium* (Figure 3 (d) – (h)).

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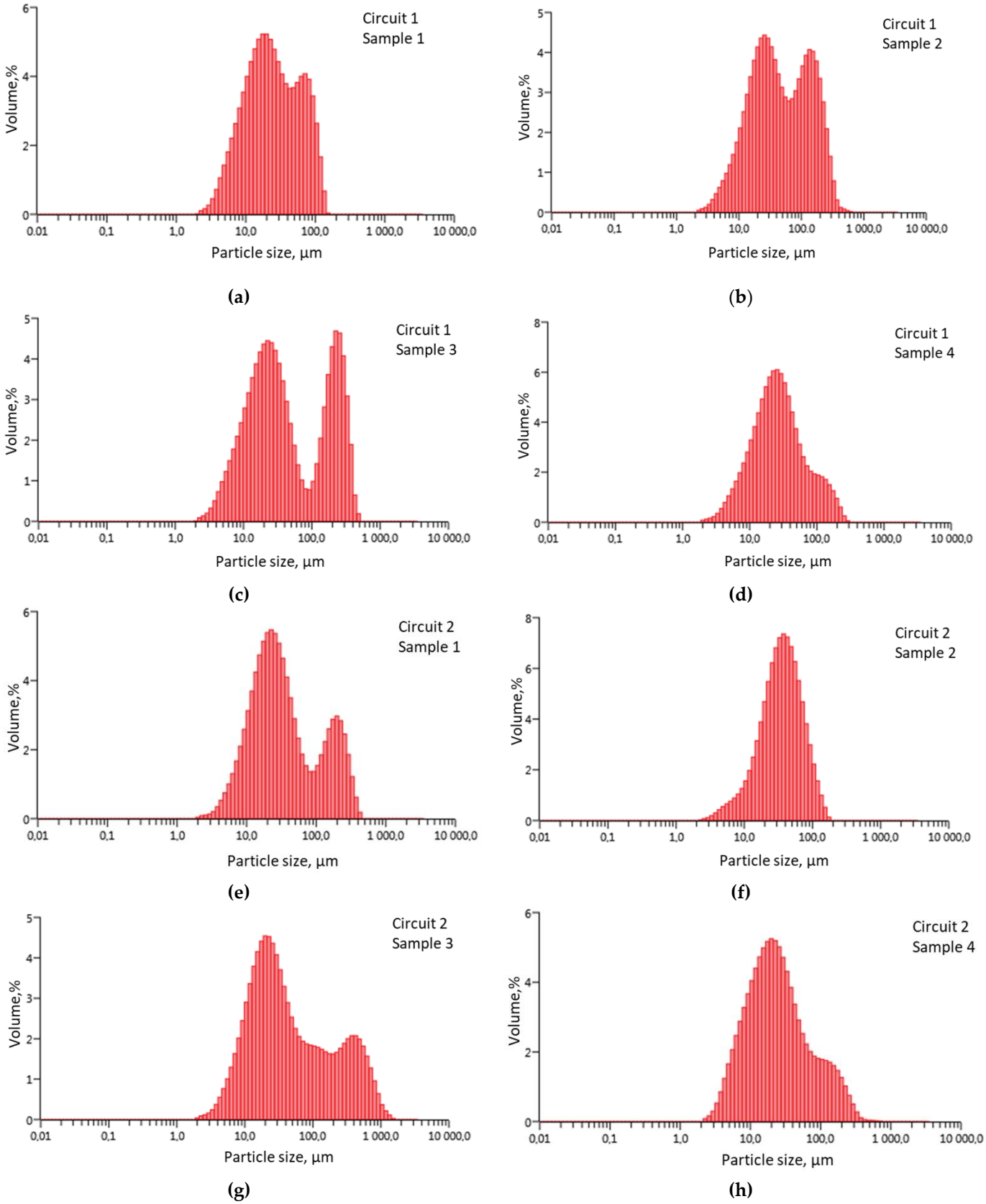

Figure 2. Particle size distribution in the analyzed washings samples (Circuit number: Sample number): (**a**) Circuit 1: Sample 1; (**b**) Circuit 1: Sample 2; (**c**) Circuit 1: Sample 3; (**d**) Circuit 1: Sample 4; (**e**) Circuit 2: Sample 1; (**f**) Circuit 2: Sample 2; (**g**) Circuit 2: Sample 3; (**h**) Circuit 2: Sample 4.

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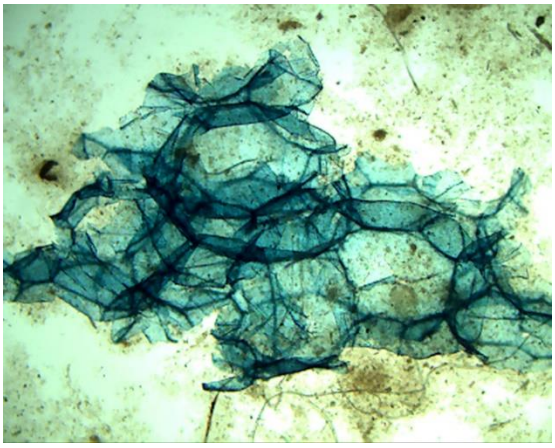
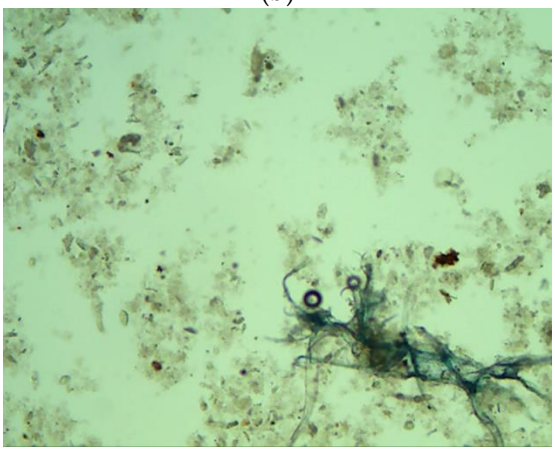


(a)

(b)

(c)



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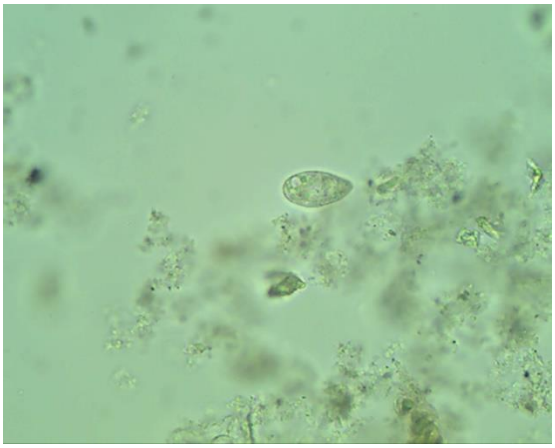

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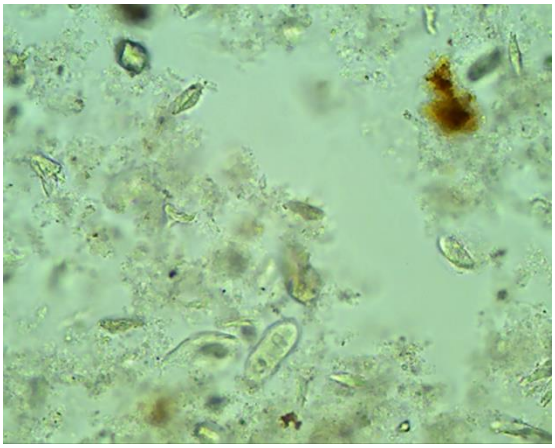

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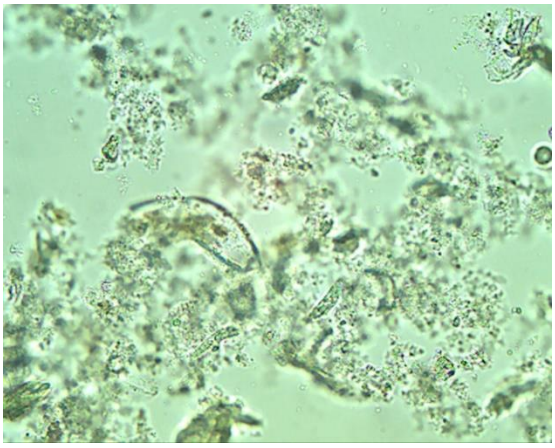
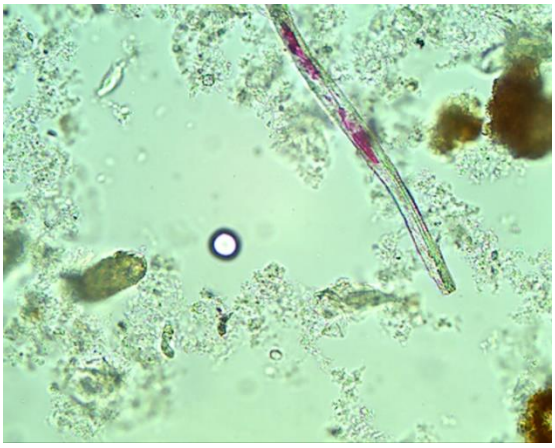


(g)



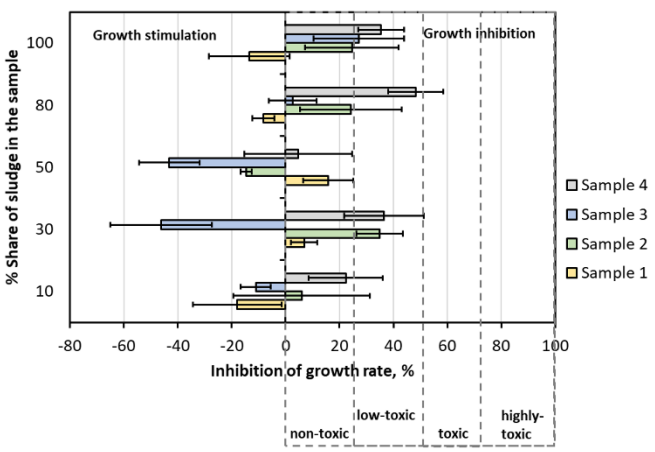
(h)

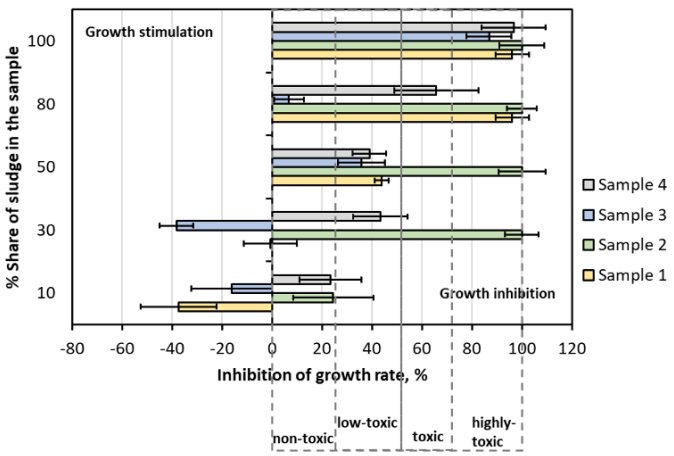
Figure 3. Photographs of the tested sediment samples taken with an optical microscope at x10 magnification (Circuit number: Sample number): (**a**) Circuit 1: Sample 1; (**b**) Circuit 1: Sample 2; (**c**) Circuit 1: Sample 3; (**d**) Circuit 1: Sample 4; (**e**) Circuit 2: Sample 1; (**f**) Circuit 2: Sample 2; (**g**) Circuit 2: Sample 3; (**h**) Circuit 2: Sample 4.

3.2. Phytotoxicity assessment of the sludges

Figures 4 (a-d) present the toxic effect of sludges on the common duckweed *Lemna minor* – inhibition/stimulation of growth and the number of necroses observed (individual values are listed in Table 1S in the Supplement). It was demonstrated that samples of sludges differed in the level of the toxic effect depending on the circulation investigated (1 or 2), as well as the independent sampling (Sampling 1÷4). Moreover, relationship between increase of sludge contribution in sample and increase of inhibition was not noted in all of the presented cases. None of the samples collected in Circulation 1 (Figures 4(a)) demonstrated toxicity, mean values of growth inhibition did not show toxicity or were characterized by low toxicity. In the case of some samples growth stimulation was observed (for instance Sample 1 and 3 with sludge contribution of 10%). In the samples w 100% sludge contribution samples 3, 4 exhibited low toxicity. The highest number of necroses was recorded in sample 4, with 80% sludge contribution (Figure 4 (c)) - 45% of duckweed were damaged and this result was reflected by the value of growth inhibition, which under such conditions was also at its highest – 48.21% ± 10.20.

Samples from Circulation 2 were characterized by higher inhibition of growth of *Lemna minor* (Figure 4 (b)). All analyzed samples with 100% sludge contribution and majority of samples with 80% sludge contribution were characterized by high toxicity. Significantly, sample 2 was characterized by a high toxicity already at 30% sludge contribution, and in this case the toxicity was also reflected by the higher number of necroses found (Figure 4 (d)), from 75 to up to 100% of duckweed coverage.





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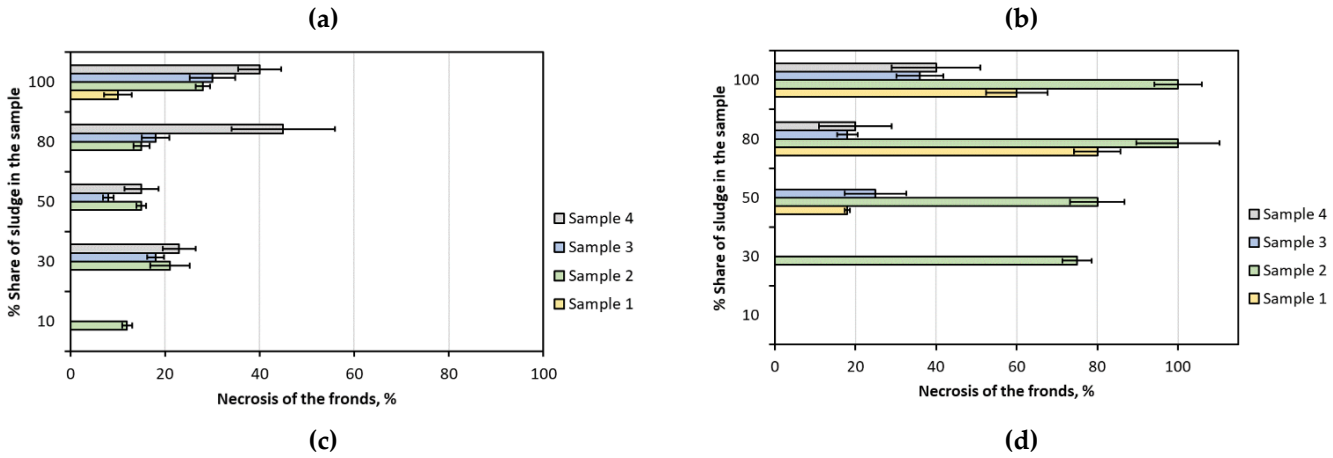

Figure 4. Sludge phytotoxicity evaluation (Circuit number: Sample number): (**a**) Circuit 1: growth inhibition of *Lemna minor*; (**b**) Circuit 2: growth inhibition of *Lemna minor*; (**c**) Circuit 1: % necrosis of *Lemna minor* fronds; (**d**) Circuit 2: % necrosis of *Lemna minor* fronds.

The second part of the phytotoxicity assessment focused on the parameters of root growth and germination rate – *Lepidium sativum*, *Sinapis alba* and *Raphanus sativus* (full data available in the Supplement Table 2S – 7S). In tests with *Lepidium sativum* (Figures 5(a-d)) in the majority of samples analyzed, toxicity of the collected sludges was recorded (in Circulation 1, sample 1 in the range 30÷100%, sample 2, sludge contribution: 30, 80, 100%, sample 3 in the range from 50 to 100% of sludge). In the case of sample 4 from Circulation 1 and sample 3 from Circulation 2, toxicity was found throughout the range of sludge contribution (this data is also presented in the Supplement, Table 4S). On the other hand, sample 2 from Circulation 2 was non-toxic/demonstrated growth stimulation. At the same time, in the majority of the analyzed samples inhibition of germination was recorded, the value of which increased with the percentage contribution of sludge in the samples (Figure 5 (c, d)). Higher toxicity was recorded for samples from Circulation 1, and thus the results were largely contrary to those recorded in the test with *Lemna minor*. Also, in tests with *Sinapis alba* (Figures 6(a-d)) toxicity of the majority of samples from Figure 1 was obtained. These results were not confirmed in the test with *Raphanus sativus* (Figure 7(a-d)), in which only some samples with 100% post-coagulation sludge contribution demonstrated high toxicity (Figures 8(a-d)), whereas the majority of analyzed sludges stimulated the growth of *Raphanus sativus* roots. Causes for this phenomenon should be searched not only in the diverse sensitivity of the test plant organisms to the investigated sludges, but also in the effect of pollutants present in the post-coagulation sludges on the growth and development of plants. Growth stimulation may be caused by low aluminum concentration [26-28].

Worth noting are the values of the RSG index (Relative Seed Germination, %), which are presented in the Supplements, in many samples a relationship could be observed between the increase of sludge contribution in sample and inhibition of seed germination (Supplement: Table 3S, 5S, 7S).

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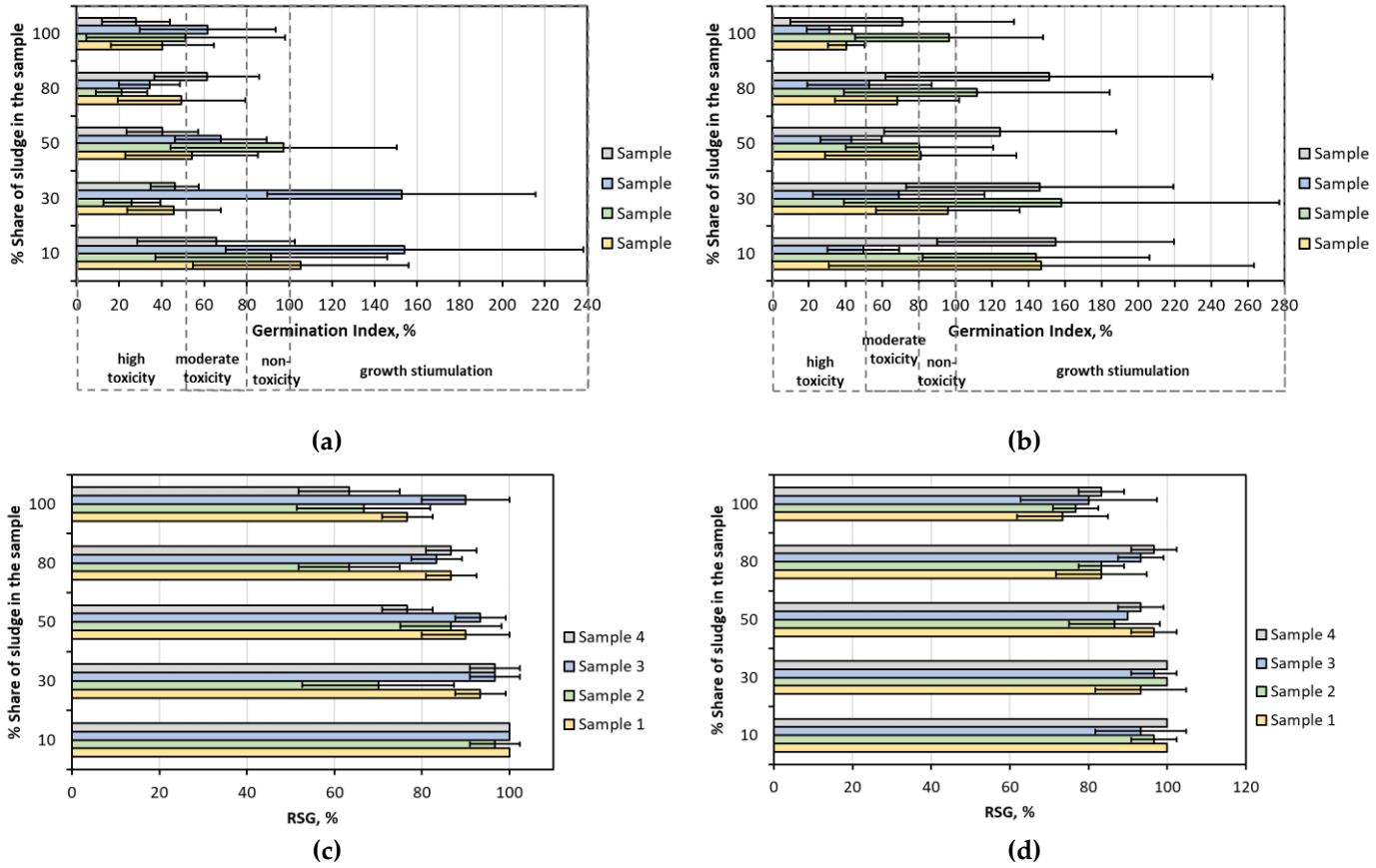
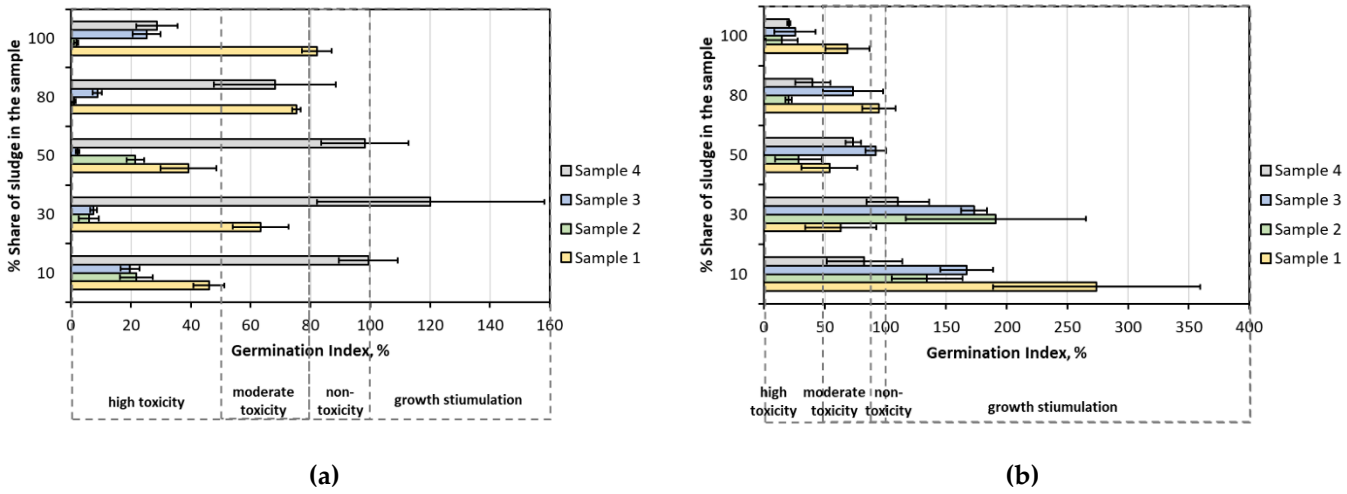


Figure 5. Sludge phytotoxicity evaluation (Circuit number: Sample number): (**a**) Circuit 1: Germination Index for *Lepidium sativum*, %; (**b**) Circuit 2: Germination Index for *Lepidium sativum*, %; (**c**) Circuit 1: Seed germination for *Lepidium sativum*, %; (**d**) Circuit 2: Seed germination for *Lepidium sativum*, %.



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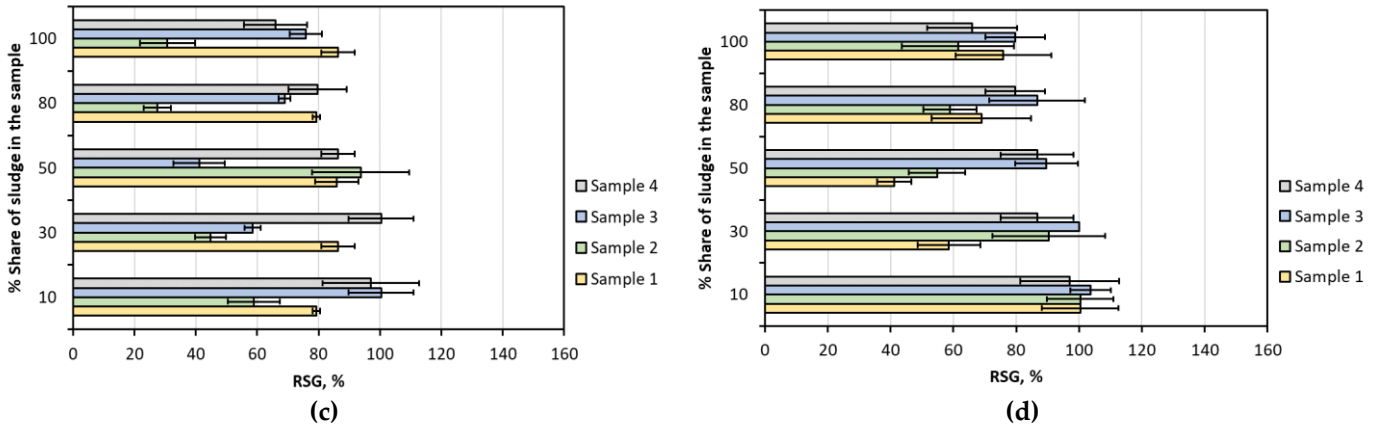

Figure 6 Sludge phytotoxicity evaluation (Circuit number: Sample number): (**a**) Circuit 1: Germination Index for *Sinapis alba*, %; (**b**) Circuit 2: Germination Index for *Sinapis alba*, %; (**c**) Circuit 1: Seed germination for *Sinapis alba*, %; (**d**) Circuit 2: Seed germination for *Sinapis alba*, %.

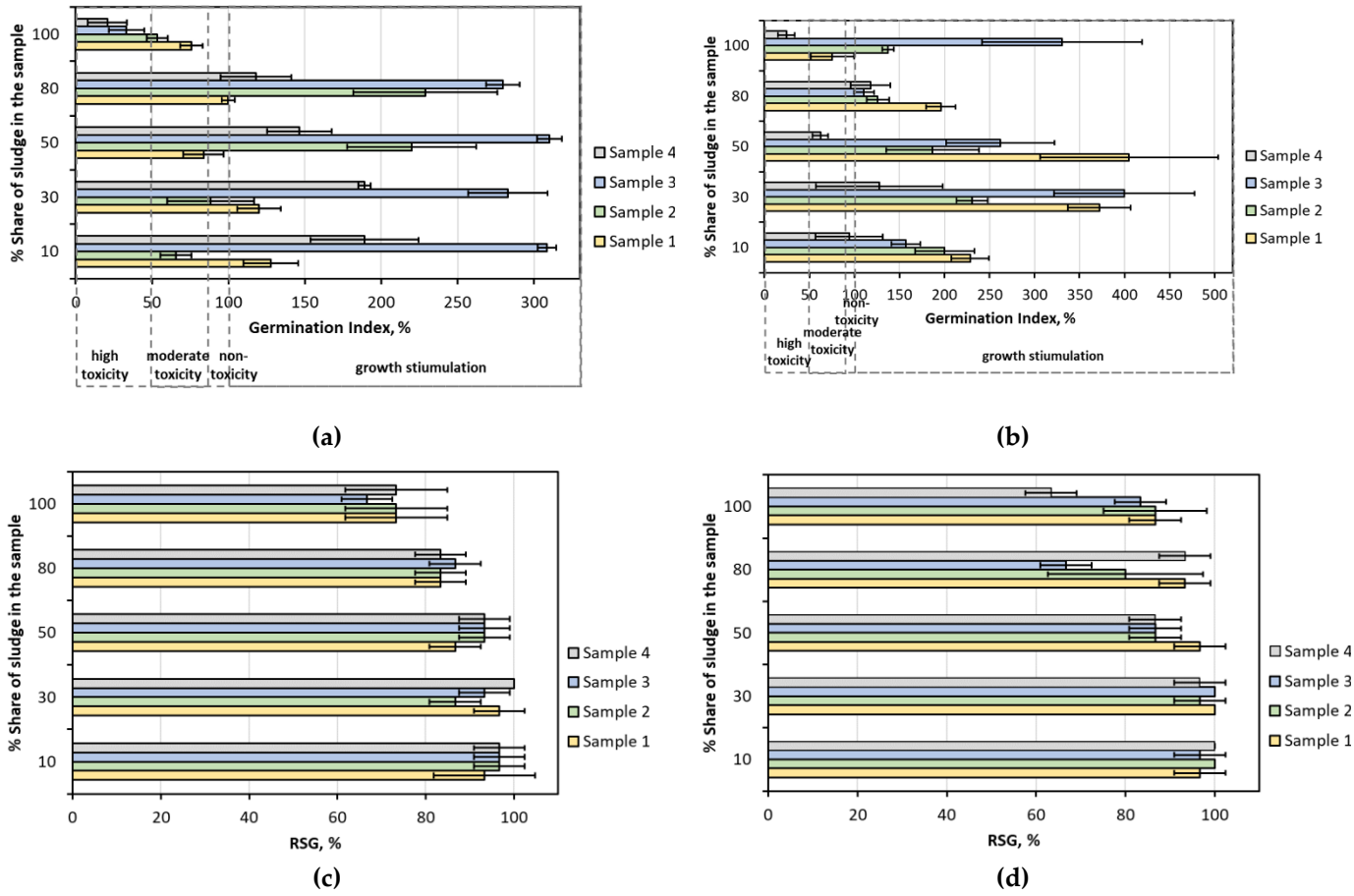

Figure 7. Sludge phytotoxicity evaluation (Circuit number: Sample number): (**a**) Circuit 1: Germination Index as *Raphanus sativus*, %; (**b**) Circuit 2: Germination Index as *Raphanus sativus*, %; (**c**) Circuit 1: Seed germination as *Raphanus sativus*, %; (**d**) Circuit 2: Seed germination as *Raphanus sativus*, %.

4. Discussion

Coagulation process is utilized in swimming pool facilities to support the filtration process by means of porous substrate, increasing the efficiency of removing organic compounds [29]. Coagulant is added directly upstream of the pump with prefilter, which ensures its good mixing with water. Subsequently, the precipitated sediment, depending on

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the size of aggregates they are retained on the surface or gradually migrate inside the filtration medium which prolongs the contact time with pollutants in the water and increases the efficiency of their adsorption. Ready-to-use commercial products containing several percent aluminum salts (hydrolyzed or non-hydrolyzed) are typically used at swimming pool facilities [3, 30].

In order to maintain good water quality in the pool it is necessary to regularly remove sediments and pollutants accumulated in the medium. The quality and amount of sediments depends on a variety of factors, including the length of the filtration cycle, load of the facility with people using the pool, hygiene habits of the pool users, frequency of exchanging water in the entire circulation, or the type and concentration of chemicals used for cleaning [3,17,31]. In the presented analyses the quality of sediments clearly differed between the subsequent samplings, as well as between the circulations. Diverse sedimentation capabilities, as well as volumes of the sediment obtained were characterized. Importantly, no clear relationship between the broader distribution of particles found in the sediment (their greater equivalent diameter) and their reduced settling velocity (Figures 1(a-h), Figures 1(a-h)). However, the results show that the quality of washings and the sediment present therein is difficult to estimate, and it often depends on the conditions that occurred in the given filtration cycle, e.g. sampling on a day of intensive use of the pool by school youth, swimming classes or days off work when the load on the facility is greater. Thus, the load is the key factor affecting the quality of washings and the amount of pollutants deposited in the post-coagulation sediment.

The washings forming during the backwashing contain several percent of sediment (in the presented study this amounted to 2 to 7.5%). The analyses available in the literature focus on the sediments formed in the process of potable water treatment, where the sediment constitutes approximately 5% of washings volume [30,32]. Washings with sediment are typically treated as wastewater and transferred directly to the sewage system. They include not only the precipitated flocculi but also mechanical impurities (hair, fibers from clothing, epidermis) and microorganisms, some of which are pathogenic [29]. Presence of this type of impurities was confirmed also for samples analyzed by the author. The washings were found to contain bacteria *Pseudomonas aeruginosa*, *Escherichia coli*, coagulase positive staphylococci, *Legionella sp.* and *Cryptosporidium Parvum* oocysts [33-35].

Considering the chemical characteristics, the post-coagulation sediments can also contain minor amounts of metals, i.a. Fe, Ca, Cr, Zn, Pb, Ni, Cu, Cd, Mg and Mn [29,36]. As well as considerable amounts of aluminum. Kluczka et. al., 2017, examined post-coagulation sediments (from the process of water treatment) comparing their quality with wastewater sediments, and determined that both sediments meet the requirements of the Polish Regulation of the Minister of Environment of 6 February 2015 on the concentration of heavy metals and can be used in agriculture. The total sum of lead, cadmium, nickel, copper and chromium was considerably lower than the permissible values, and the metals were found as residues (with the exception for cadmium bound with organic matter). Although the amount of tested exchangeable aluminum was low in both sediments, the concentration of the bioavailable aluminum in the post-coagulation sediment was considerable [36]. During the coagulation process it is highly important to maintain the neutral pH, which prevents the release of mobile aluminum (III) ions, which increase toxicity of the sediment and disturb the physicochemical properties of water. In practice, in swimming pool circulations the pH values range between 6.5 and 8.0 [37,38], which may increase the risk of toxic aluminum. Aluminum coagulants with differing characteristics were used in the presented circulations. In Circulation 1 it was non-hydrolyzed (aluminum sulfate (8.5%)), In Circulation 2 it was pre-hydrolyzed (aluminum hydroxychloride (10%)). Pre-hydrolyzed coagulants are characterized by the fact that they contain hydroxyl groups that determine their increased alkalinity. When polyaluminum chlorides are produced, sulfates and silica can be added to their solutions, increasing sedimentation of post-coagulation suspensions. It is estimated that lower doses of pre-hydrolyzed coagulants enable obtaining the same effects as in the case of non-hydrolyzed coagulants. Moreover, they

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reduce pH to a lesser degree, and their efficacy is not as strongly dependent on temperature [39]. In the analyzed case the type of coagulant was the determining factor for the sedimentation capabilities, but it did not determine the amount of sediment or particle size distribution. The determined mean TSS reduction level, % was for Circulation 1, for sample 1, 2, 3, 4, respectively: 88.96; 86.59; 80.27; 76.37, and for Circulation 2: 92.38; 92.65; 89.23, 84.54 (data not presented in Chapter ''3. Results''). However, no direct relationship between the type of coagulant (pre-hydrolyzed/non-hydrolyzed), and the toxic effect towards indicator organisms. The preliminary amount of total suspended solids did not impact the phytotoxic effect.

Despite the extensive presence of waste from water treatment processes, literature on the topic of potential toxicity of post-coagulation sediments is rather limited and the results are often conflicting [40]. Traditional solutions in the field of waste management include the use of post-coagulation sediments as the agent for impurity removal (e.g. adsorbent of heavy metals and phosphorus) [30,41]. In the past, post-coagulation sediments were viewed as inert waste material, with low reuse possibilities, thus they were removed directly to waters. Only later were they considered toxic for living organisms due to the presence of aluminium [41]. That is why they are typically dried and stored or incinerated, which naturally brings about financial costs. Storage is linked to land use, and the incineration process is poorly accepted by the society and is efficient only in the case of sediments with low moisture content. That is why different ideas for the management of waste have been proposed, e.g. as an additive to construction materials [41-43].

The concerns related to the use of post-coagulation sediments in the contact with plants, in agriculture and gardening are mostly related to the potential negative effects of accumulation of certain heavy metals (in particular aluminum), which may pose hazard to organisms of higher order. Moreover, the conditions ensuring a balance between aluminum and phosphorus ions are still not clear [44]. On the other hand, other authors have emphasized that due to the content of carbon, hummus substances and the alkaline properties enriching soil, the addition of post-coagulation sediment may play the role of buffer [29,30]. The use of sediments may improve the structure, hydraulic conductivity, humidity and level of nutrients in soil, because it contains a considerable amount of macro- and micronutrients and organic matter [40]. However, development of modern analytics and toxicology brought a deeper insight in the negative effect of aluminum on the environment and living organisms.

The issue of aluminum migration from post-coagulation sediments is related to the acidic pH of soil, thus in the presented study an attempt was made to ensure neutral conditions (dissolving specific percentage contributions of sediment in deionized water). This will enable including a broader effect of environmental factors in future analyses. Phytotoxicity of aluminum is related directly to the environmental conditions that control solubility of the element in soil [40].

The ionic form of aluminum (Al^{3+}) is believed to be toxic for plants already at micromole concentrations [45]. Some plants developed tolerance mechanisms through developing complexes of organic acids with aluminum, in the leaves or in the rhizosphere [45,46]. Being highly reactive, ionic aluminum hits the cell wall, cytoplasmic membrane, nucleus and the cytoskeleton of plants' roots. It affects the function of the mitochondria due to the overproduction of free radicals. Thus, it has a multi-level, harmful effect on plants. The symptoms also include morphological traits. Growth inhibition, reduced leaf surface area, wilting and increased incidence rate of chloroses are also observed [29,45]. These reports are confirmed in the study. Inhibition of growth, germination and increased incidence rate of necroses was often linked to increased percentage contribution of sediments in samples. However, the determining factor for the obtained level of toxic effect was the resistance of the plant indicator - the highest resistance to post-coagulation sediment in the case of *Raphanus sativus*, highest sensitivity in the case of *Sinapis alba*. Moreover, important differences in the values obtained between subsequent conditions were

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recorded, which confirms that the quality of washings and sediments changes with the subsequent filtration cycles.

Despite the knowledge of the toxic effect of aluminum on living organisms, possibilities for using post-coagulation sediments on agricultural areas are still considered. This stems mainly from the growing need to seek new solutions in the field of circular economy in the water and sewage sector. The concept focuses on using also waste raw materials, thus reducing their squandering. The water and sewage management is facing a multitude of challenges, because the climate change is inherently linked to the intensification of the water crisis [47]. Water is the carrier of materials and energy, which ought to be used in a more sustainable manner in the modern world.

5. Conclusions

Preliminary assessment of the quality of post-coagulation sludges originating from rinsing of filtration media enabled formulating a series of observations and conclusions:

- The tested post-coagulation sludges were characterized by high content of total suspended solids: in samples from Circulation 1 from 251 to 128 mg/l, in Circulation 2 from 489 to 228 mg/l.
- The sludges were concentrated gravitationally and the volume contribution of sludge in the washings was from 2 to 7.5 %.
- The hydrolyzed coagulant (Circulation 2) contributed to the improvement of sedimentation capabilities of sludges.
- The concentrated sediments, apart from the flocculent suspension, contained numerous other solid impurities - material fibers, hair, sand and hydroanthracite particles (washed out of the filter bed during backwashing), as well as microorganisms. Sludge particles had a wide size distribution from 1.0 to 1000 μm, while other solid impurities were from a few millimeters in diameter (bed fragments) to even several millimeters in length (in the case of fibers).
- No direct relationship could be observed between the type of coagulant (hydrolyzed/non-hydrolyzed) and the toxic effect among the tested test organisms.
- The results of the toxicity assessment indicate that the post-coagulation sludge may pose a hazard to plants. Although growth stimulation was noted in some of the tested samples - in the case of tests with Lemna minor and Raphanus sativus, it must remember that the consequences of long-term contact of plants with post-coagulation sediments from swimming pool facilities is unknown.
- In this case, the next research step is to extend the analyzes with pot experiments, in which sludges could be an admixture to the soil.
- The presented results are also important from the point of view of the potential for the management of the washings themselves. Recognizing the strength of the threats posed by post-coagulation sludge allows establishing a strategy for cleaning the washings before using them, for example, for greenery care.

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