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Experimental Research on Residual Chlorine Removal from Stormwater

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Abstract: In recent decade water pollution by micropollutants is an increasing environmental concern. Since 2019, due to COVID-19 pandemic, increased stormwater pollution by chlorine based disinfectants has been determined. Research aimed to treat of chlorine contaminated stormwater after outdoors spaces disinfection are very limited. Runoff from disinfected areas and residual chlorine present in stormwater are transported to surface water bodies. Residual chlorine reacts with dissolved organic compounds in water and results the formation of environmentally toxic disinfection by-products. Studies present event low residual chlorine concentrations may pose a risk to aquatic flora and fauna. In this study the efficiency of different filter materials, including peat, wood chips, sawdust (column tests) and ceramzites *Leca, Pollytag, Polski, Ceski* (batch tests), in retaining residual chlorine were tested in laboratory scale batch and flow through experiment. The best efficiency to retain chlorine presented sawdust (96 %) and ceramzite *Leca* (76 %). The plants abilities to reduce pollution by chlorine was analyzed in raised garden bed. Research results will contribute to future studies aimed to retain various micropollutants in stormwater using remediation technologies.

Keywords: micropollutants; residual chlorine; stormwater treatment; remediation technologies

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1. Introduction

Untreated stormwater contains various pollutants and is one of the main sources of water bodies contamination. Nowadays a growing environmental challenge is stormwater pollution by micropollutants which by runoff are transferred to the rivers and lakes. European Commission concerns the yearly micropollutants loads are getting worse and more complicated as well pose a long-term risk to aquatic ecosystems even at low concentrations [1]. Therefore the stormwater treatment must meet the highest requirements to avoid a negative impact on ecosystems and deterioration of rivers and lakes water quality. Proper stormwater treatment contributes to the sustainable management of water resources and the implementation of circular solutions, provides water security and resiliency as well saves water resources and improves surface water quality [2,3]. EU water policy aims to encourage and facilitates water reuse [4]. Following the recommendations of the Baltic Sea Environmental Protection Commission since the June, 2021 stormwater must be managed in a way that reduce the amount of pollutants entering the surface water bodies [5].

Studies highlight to apply green infrastructure (GI), also referred as nature-based solutions, to remove micropollutants from stormwater in order to protect surfaces water bodies. GI complements grey infrastructure, as well contributes to existing infrastructure cost reduction and economic

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development [6,7]. However urbanization, frequent natural disasters caused by climate change make grey infrastructure less effective and call cities for innovative green stormwater management solutions [8]. Cities are encouraged to apply nature-based solutions to mitigate negative effects of climate change. Integration of green infrastructure in stormwater management systems is an effective tool to retain and absorb pollutants [9–11] as well the application of natural sorbents, vegetation and soil's sorption ability contributes to remove various harmful substances. The major advantages of green infrastructure is not only the increased environment protection, but also creation of aesthetically attractive landscape or additional recreational spaces, thus improved life quality [12,13].

This article is focused on discussion of possible filter materials and remediation technologies to reduce residual chlorine concentrations in stormwater. The need to analyze chlorine and chlorine compounds impact on surfaces water have raised during the pandemic when countries applied intensive public spaces disinfection. Studies present environment pollution by chlorine based substances due to public outdoor disinfection went up several times. The outdoor surfaces (SPA centers, nursing homes and etc.) need to apply permanent disinfection to avoid the spread of infections and viruses [14]. It resulted disinfected surfaces are washed by runoff and stormwater containing chlorine are stored in reservoirs. The increased amount of residual chlorine and disinfection by-products have been found in rivers and lakes [15–18]. Other studies show, that some countries use swimming pools water for irrigation of green areas [19]. It contributes to release of residual chlorine into environment.

Chlorine can be present in water as free residual chlorine and as combined chlorine. Residual chlorine is the low level amount of chlorine remaining in the water after a certain period or contact time after its initial application. Studies show the formation of free residual chlorine depends on the dose of sodium hypochlorite [20,21]. Residual and combined chlorine exist in the same water and are determined together as the total chlorine. (Figure 1). Free residual chlorine is present as hypochlorous acid or hypochlorite ion. Combined chlorine exists as monochloramine, dichloramine, nitrogen trichloride, etc.

Free Residual chlorine composed of dissolved hypochlorite ions, hypochlorous acid and chlorine gas	**Combined** Composed of chloramines and other organic compounds	**Total** The sum of free residual and combined chlorine

Figure 1. Chlorine forms in water.

Chlorine and chlorine compounds influence formation of harmful secondary products which pose risks to aquatic environment [22–26]. Studies present impact of residual chlorine on various water microorganism remain up to 14 days and even low concentration of chlorine with continuous impact could affect water ecosystems. The impact on aquatic fauna were detected at low chlorine concentration [27]. The outdoor disinfection by sodium hypochlorite causes also surface corrosion due to strong oxidizing features of chlorine and its reaction with almost all metals and non-metals [28–30]. These findings raise a concern about the adverse effects of chlorine and its compounds on the environment due to intensive public spaces and surfaces disinfection [31]. Increased use of chlorine based disinfectants and residual chlorine toxicity in water bodies raised the need to analyze residual chlorine impact on water environment and provide with the possible methods and materials of its reduction. Previous studies found out that stormwater contaminated by chlorine and chlorine compounds can be treated using natural sorbents. The novelty of this research is to analyze wasted materials and phytoremediation efficiency of residual chlorine removal. The retain of residual chlorine depends on the following characteristics: structure of filter material, material's particle size, pore dimensions, pore volume and specific surface area [32]. Present research was conducted with the following specific objectives: (1) to evaluate the efficiency of different low cost and recyclable

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filter materials to retain residual chlorine; (2) to test plants efficiency to reduce residual chlorine concentration by phytoremediation; and (3) to provide with findings on materials could be used in green infrastructure in order to reuse stormwater.

2. Materials and Methods

Research were conducted in laboratory (column and batch) and a field experiment (raised garden bed) to assess the efficiency of various natural, low-cost, and recyclable filter materials in retaining residual chlorine and preventing its release into the environment. Column and batch tests addressed to analyse different materials capacities to reduce chlorine concentrations. Raised garden bed was used to assess plants phytoremediation capacities as well as combined effect of plants and substrate to reduce chlorine pollution. Research materials were chosen considering their efficiency to remove pollutants from stormwater, as well as following the main principles of sustainability (cheap waste materials, accessible on the market of European Union). Experiments carried out using following materials (Figure 2):

- *Peat* (0.1-5 mm) is an inexpensive and effective sorbent suitable for removing various environmental pollutants [33]. Peat has good adsorption properties for suspended and dissolved solid particles, and is often used as an effective filter material. Decomposed peat has a relatively high porosity of about 95%, with a specific surface area of 200 m^2 /g.

- *Wood chips* (20-50 mm) *and sawdust* (0.1-2 mm) are wood by-product, waste material and low-cost sorbent applied mainly for removal of organic compounds from wastewater [34] as well used in green infrastructure in order to retain pollutants in stormwater before they enter the environment by runoff. Benefits of wood chips include their potential effectively retain and slowly release moisture; they are relatively cheap to purchase; provide weed control; may sequester some pollutants.

(a) (b) (c)

Figure 2. Filter materials used in experiments: (**a**) Peat; (**b**) Wood chips; (**c**) Sawdust.

- *Pollytag* (fraction 8-11 mm) is cheap adsorbent material, produced by granulating and sintering fly ash at a temperature of 1000–1350 °C. *Pollytag* is characterized by good physical properties (high porosity, low water absorption) which enable the material to be used as filter medium [35]. Batch tests were carried out on four lightweight materials: *Polski, Leca, Pollytag, Ceski* (Figure 3).

(a) (b) (c) (d)

Figure 3. Researched materials: (**a**) Ceramzite *Polski*; (**b**) Ceramzite *Leca*; (**c**). Ceramzite *Pollytag*; (**d**) Ceramzite *Ceski.*

Previous studies showed that *Pollytag* and *Leca* can retain pollutants in green constructions [36]. *Pollytag* is a commercial product manufactured of fly ashes from a thermal-electric power station. Lightweight aggregate *Pollytag* due its efficient absorption features is used in green constructions as a water retention layer. The main compounds are SiO_2 (58%), Al_2O_3 (22%), CaO (2.2%) and MgO (1.4%). *Leca* is a light expanded clay aggregate contained small particles of burnt clay. It is used as a construction material for flooring and roofing as well for bio-filtration (wastewater treatment) and agriculture. The main compounds are SiO_2 (54%), Fe_2O_3 (14%), Al_2O_3 (12%), MgO (2%), CaO (0.6%). *Polski* is a natural, processed mineral with good absorption properties, used for pollutants removal. *Ceski* is a light expanded clay aggregate stone widely used in gardening, building construction industry.

Sodium hypochlorite (NaOCl) is a clear, yellow colored solution with a pungent smell. NaOCl is an effective disinfectant widely used for surfaces, public spaces and pools decontamination. NaOCl is characterized by high energy consumption a strong corrosive effect, is toxic for aquatic environment. Its molar mass is 74.44 g/mol; density - 1.11 g/cm³; melting point - 18 °C; boiling point - 101 °C. WHO recommend to apply (1000 ppm) concentration for disinfection [37].

Test water and collected leachates were analyzed for residual chlorine with *Chlorine meter CL200 ExStik* with measuring range from 0.01 ppm to 10 ppm, accuracy ±10% of reading ±0.01 ppm, temperature range -5 to +90⁰C, automatic self-calibration, complies with ISO-9001.

Column experiment. Column test includes glass columns (diameter 5 cm) filled with ceramzite (*Pollytag*, fraction 8-11 mm) as drainage layer (20 cm) as well with different filter materials (peat, wood chips, sawdust, every layer of 20 cm) (Figure 4) and 2000 ml solution made from stormwater synthetically polluted by sodium hypochlorite (following WHO recommendations 1000 ppm). Test samples were collected at stormwater outlets in territory permanently disinfected by sodium hypochlorite. Samples were placed into hermetically sealed containers (10 l) and transported to the laboratory. The first experiment was conducted using peat (0.1-5mm) as filter material, second experiment – using wood chips (20-50 mm) and the third one – using sawdust (0.1-2 mm). After a contact time of 30 min the sample was measured for pH, conductivity, turbidity, color intensity and residual chlorine. Each experiment have been repeated three times.

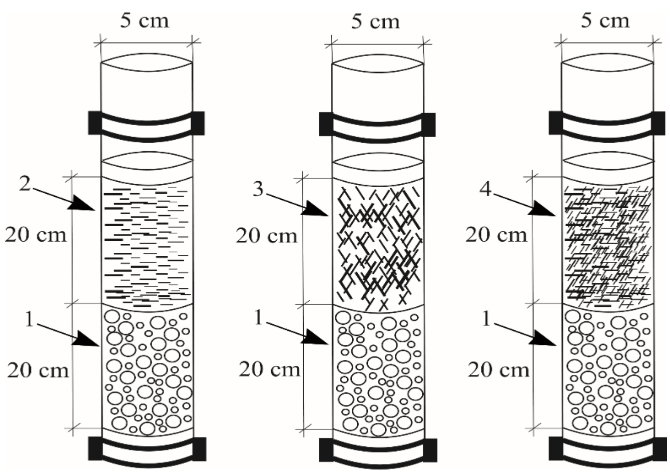

Figure 4. Column test: 1-Ceramzite (*Pollytag*); 2- Peat (0.1-5 mm); 3- Wood chips (20-50 mm); 4- Sawdust (0.1-2 mm).

Batch test. Batch experiments were conducted to determine the capacities of diferent types of drainage construction materials (ceramzite) to absorb residual chlorine. For batch sorption test glass jars (diameter 7 cm) were filled with 5 cm of tested material – different types of ceramzitte and test 450 ml solution prepared mixing synthetic stormwater with sodium hypochlorite concentration

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following WHO recommendations (1000 ppm). At first stage three glass jars (J1, J2, J3) were filled with Polski (J1 - 159. 93 g; J2 - 178. 36 g; J3-155, 34) and three glass jars (J4, J5, J6) were filled with Leca (J4 – 65.16; J5-71.70; J6 – 72.43 g) (Figure 6). After contact time of 30 min was measured the concentration of residual chlorine mg/l.

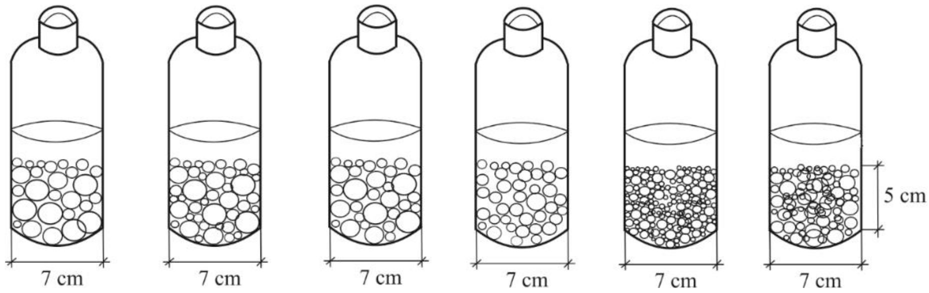

Figure 5. Column test: 1-Ceramzite (*Pollytag*); 2- Peat (0-5 mm); 3- Wood chips (20-50 mm); 4- Sawdust (0-2 mm).

At second stage batch experiments have been repeated changing ceramzite type and filling three glass jars (J7, J8, J9) with Pollytag (J7 – 172,51g; J8-185,02g; J9 – 159,75g) and three glass jars (J10, J11, J12) with Česki (J10-181,97g.; J11-187,53g; J6 – 190,73g). After contact time of 30 min the concentration of total (residual) chlorine was measured with *Hach DR/2400 Portable Spectrophotometer*. Device is applied for testing residual amd total chlorine and chloramines in water, wastewater, storm water and etc. estuary water, seawater. Using *Hach DR/2400* samples must be analyzed immediately and cannot be preserved for later analysis. After adding the reagent (DPD total chlorine reagent powder pillows, 10 ml), a pink color will develop if chlorine present.

Raised garden bed. Field test was carried out to analyze plants capacities to filter stormwater and retain residual chlorine entered to stormwater after surfaces disinfection. A raised garden bed cros section is presented on Figure 6.

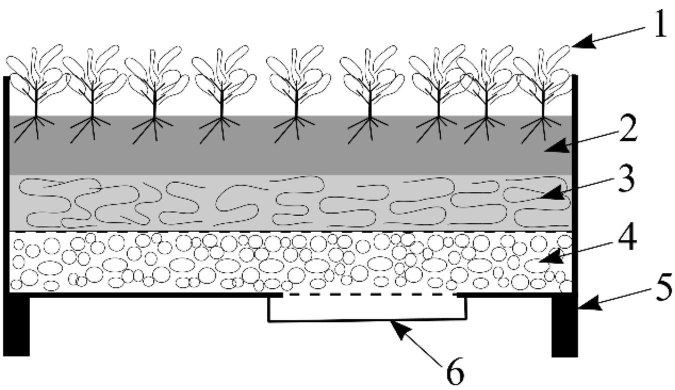

Figure 6. Raised garden bed: 1. – Plants; 2. - Peat layer (15 cm); 3.-Water filtering layer (10 cm); 4.– drainage layer (ceramzite, 5 cm.); 5. – Wooden bed frame; 6. – Water tank.

Test garden bed includes wooden bed frame (1 meter long and 1 meter width), filled with peat layer (15 cm), water filtering layer (Rockwool, 10 cm), drainage layer (ceramzite *Leca* 5 cm) and the reservoir to collect stormwater runoff. Materials for test bed construction have been selected considering the construction layers applied in green infrastructure. Studies present that efficiency of pollutants removal depend on construction materials. The purpose of water-filtering layer is stormwater filtration as well protection of the drainage layer against fine particles present in soil substrate. Rockwool is used as water filtering layer because its proper medium for plant roots (provides the conditions to enter of oxygen) and is characterized by good absorption capacities. Research revealed drainage layer must be resistant to cold and mechanical impact, chemically neutral, harmless to plants, and contain the ability to drain the excess water (citavimas). Ceramzite is

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resistant to chlorine, has low density and does not load the structure [32]. Ceramzite *Leca* (fraction of 10-20 mm) was used for drainage layer because its characteristics improve roots breathing, eliminate weed, provide porosity, and rot-resistance.

For the first field test: *Tagetes patula* and *Pisum sativum* - annual plants that do not require an intensive care, with the excellent flowering and foliage characteristics were selected. In order to achieve a high pollutants removal degree it is very important to choose the proper plants [38]. The pollutants removal efficiency depends on oxygen and nutrient concentration, temperature, pH and other abiotic factors [39,40]. Studies present the organic pollutants removal efficiency by plants is about 56.56% and 50.25% [41]. *Tagetes patula* and *Pisum sativum* have been selected according their excellent adsorption properties and their phytoremediation capacities to retain organic pollutants [42,43].

During the experiment plants were planted in the beginning of June and continuously watered with solution of stormwater and sodium hypochlorite (concentration of 1000 ppm according to WHO recommendations) to find out how they react to residual chlorine. In the middle of November, the plants were harvested and transported to the laboratory for analysis. The samples were dried and dried test samples were have been analyzed with an X-Ray analyzer to measure chlorine and other compounds.

3. Results and Discussions

Research were carried out to investigate how different filter materials with low environmental impact (e.g., recycled materials) retain residual chlorine present in stormwater after outdoor spaces disinfection processes. Previous studies confirm the efficiency of natural filter materials (sorbents) to retain pollutants from stormwater [44]. Our experiments revealed that all materials used in laboratory tests removed residual chlorine from stormwater and affected conductivity, pH, turbidity and color.

3.1. Column experiment

Column test experiment conducted using peat with fraction size 0.1-5 mm, wood chips with fraction size 20-50 mm and sawdust with fraction size 0.1-2mm, as well synthetic stormwater test samples contaminated by sodium hypochlorite with concentration following WHO recommendations (1000 ppm). First experiment was carried out using peat layer with 20 cm as filter material. Control test using initial stormwater test samples conducted to evaluate testing water indicators (pH, conductivity, turbidity).

Table 1 present indicators values of initial stormwater before and after filtration. Experiments revealed that amount of residual chlorine is washed by runoff and enters the environment. Control test determined that stormwater samples filtration using peat as filter material have increased water indicators values.

Table 1 shows pH medium value before filtration is 6.92 meanwhile after filtration obtained medium value is 7.46, conductivity medium value before filtration is 92.6 μs/cm, after filtration - 189.4 μs/cm, as well turbidity medium value before filtration is 0.15 NTU after filtration - 0.21 NTU. It is assumed that the changes of stormwater indicators might be influenced by these factors: the contact between test sample and filter material as well the type of filter material.

Table 2. Stormwater indicators before and after filtration.

Value	pH	Conductivity, μs/cm	Turbidity, NTU
	Initial Stormwater/ After filtration	Initial Stormwater/ After filtration	Initial Stormwater/ After filtration
Minimum	6.66/7.05	86.5/118.5	0.10/0.15
Medium	6.92/7.46	92.6/189.4	0.15/0.21

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Maximum	7.74/8.07	100.6/429.0	0.19/0.38

Next stage of column test conducted aimed to investigate peat capacities to retain residual chlorine conducted using the stormwater synthetically polluted by sodium hypochlorite (1000 ppm, WHO recommendations). Measured stormwater indicators (pH conductivity, turbidity, color) and the concentration of residual chlorine are presented in Table 2.

Table 2. Retain of residual chlorine by peat filtration (Experimental runs of I, II, III, IV, V, VI) .

	Initial Stormwater	I	II	III	IV	V	VI
pH	7.9	5.5	6.6	5.8	6.5	5.9	6.8
Conductivity, µS/cm	2.9	649	601	569	741	524	492
Turbidity, NTU	0.173	0.041	0.003	1.543	0.180	0.005	0.007
Color, AV	1.193	0.169	0.008	0.072	0.012	0.005	0.031
Residual chlorine, ppm	<0.01	0.02	0.60	0.46	0.08	0.01	<0.01

Experiments obtained pH values varying between 5.5 - 6.8 to compare with initial stormwater pH the alkaline medium moved to acidic medium. Conductivity values varied between 492 - 501 µS/cm, color values vary between 0.003 – 0.169, AV after filtration of tested water by peat. Turbidity values after filtration vary between 0.003 - 0.180 NTU. Results present turbidity causing substances and colored substances are removed in a similar manner. Residual chlorine concentration was fixed from 0.6 ppm to below the detection limit after stormwater sample filtration by peat. The filtration efficiency of stormwater samples (synthetically contaminated by sodium hypochlorite, 1000 ppm) by peat depends on characteristics such as peat properties and the proportions of the test water. Later experiments were carried out by changing filter materials. Column test conducted instead peat using pine wood chips and pine sawdust. Table 3 present results obtained by filtering synthetic stormwater samples contaminated by sodium hypochlorite using wood chips with fraction size of 20-50 mm.

Table 3. Retain of residual chlorine by wood chips filtration (Experimental runs of I, II, III, IV, V, VI).

	Initial Stormwater	I	II	III	IV	V	VI
pH	7.5	8.9	9.8	9.9	10.1	10.1	10.8
Conductivity, µS/cm	20.9	481	553	604	581	615	522
Turbidity, NTU	1.248	1.396	1.345	1.312	1.244	1.217	1.266
Color, AV	0.128	0.224	0.192	0.163	0.130	0.119	0.142
Residual chlorine, ppm	<0.01	0.35	0.29	0.22	0.23	0.39	0.15

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Result show the pH value change from 8.9 to 10.8, the alkaline medium of stormwater test sample is determined. This can be explained by mutual reactions between the disinfectant and the natural fiber, as the conductivity ranges from 481 to 615 µS/cm. The presence of soluble substances in filter media impact on on conductivity values. Functional groups on the surface of filter medium participate in reactions occurring in interaction of solid surface and liquid. Value of turbidity vary slightly between 1.217 - 1.396 NDV, colour increased approximately twice from 0.119 till 0.224 AV. It shows that substances caused turbidity are removed faster than substances caused colour intensity. The concentration of residual chlorine after filtering with wood chips is determined from of 0.15 to 0.39 ppm. Chlorine removal efficiency by wood chips was about 84 -92 %. Table 4 present measurements when test sample were filtered by pine sawdust (fraction 0-2 mm). Studies present small sized sawdust is an effective and low cost, waste material used for the removal of various pollutants from stormwater [45,46].

Table 4. Retain of residual chlorine by sawdust filtration (Experimental runs of I, II, III, IV, V, VI) .

	Initial Stormwater	**I**	**II**	**III**	**IV**	**V**	**VI**
pH	8.3	9.8	8.3	8.1	7.6	8.3	8.6
Conductivity, µS/cm	40.6	643	600	764	671	643	639
Turbidity, NTU	1.151	1.249	1.370	1.205	1.265	1.160	1.131
Color, AV	0.084	0.104	0.118	0.089	0.131	0.080	0.067
Residual chlorine, ppm	<0.01	0.48	0.28	0.17	0.09	0.09	0.08

Test water pH indicator vary between 7.6 and 9.8 (acidic medium), conductivity changes from 124 to 764 µS/cm, as well turbidity 1.131 – 1.249 NTU and color 0.067 – 0.131, AV, to compare with initial stormwater values, turbidity and color have changed slightly after filtration. The concentration of residual chlorine after filtration is determined in the range of 0.08-0.48 ppm. It is assumed that the intensity of turbidity is influenced by the contact of the tested water sample with the filter materials. Conductivity is an important property of water, the higher water conductivity caused the higher concentrations of dissolved electrolyte ions in the water. An increase in conductivity indicates that the filter material effectively adsorbs disinfectants. Experiments determine the efficiency of sawdust to retain residual chlorine varied approximately from 80 till 96 %.

3.2. Batch test

The adsorption process was tested using the static method determining the capacities of natural outdoor covers to retain total chlorine. Different types of ceramzite were used for batch test to evaluate the adsorption efficiency of construction material. Glass jars volume 500 ml were filled with 5 cm high layer of ceramzite and with 450 ml solution with total chlorine concentration 0.2 ppm. Higher sodium hypochlorite concentration was chosen considering that some countries use higher concentrations as it was recommended by WHO for outdoor disinfection (Hu et al. 2023). After 30 min of contact time total chlorine concentration was measured. At first stage of experiment conducted test experiments using ceramzite Polski (J1, J2, J3) and Leca (J5, J6, J7) (Table 5).

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Table 5. Batch test results (Experimental runs of I, II, III, IV) .

	Ceramzite mass, g	I ppm	II ppm	III ppm	IV ppm
Initial stormwater		3.52	4.02	3.97	4.11
J1	159.93	2.00	3.36	3.84	3.80
J2	178.36	2.03	2.18	3.38	3.83
J3	151.34	2.03	3.52	3.54	3.89
J4	65.16	1.54	1.08	1.25	0.89
J6	71.70	0.87	0.72	0.81	1.97
J7	72.43	1.17	1.03	1.63	1.07

Table 5 present *Polski* (J1, J2, J3) and *Leca* (J5, J6, J7) capacities to retain total chlorine. The results indicate that *Polski* (151.34 – 178.36 g.) retained total chlorine in the range of 2.00 -3.89 ppm. Total chlorine retention by *Leca* (65.16 – 72.43 g.) is 0.81 – 1.97 mg/l. Total chlorine concentration after contact with *Polski* decreased about 1.1 -1.7 time and removal efficiency reaches approximately up to 43 %, meanwhile by *Leca* is about 76 %. It can be explained by ceramzite size, porous structure, ceramzite structure, at a higher fraction increase porosity and water immersion of ceramzite. At second stage batch test experiments repeated using following ceramzite: *Pollytag* (J7, J8, J9) and *Ceski* (J10, J11, J12) (Table 6).

Table 6. Batch test results (Experimental runs of I, II, III, IV) .

	Ceramzite mass, g	I ppm	II ppm	III ppm	IV ppm
Initial stormwater		2.26	4.06	3.56	2.08
J7	172.51	1.88	3.78	3.48	2.04
J8	185.02	1.58	3.72	3.46	1.84
J9	159.75	2.23	4.02	3.40	1.80
J10	181.97	1.92	3.86	3.32	1.82
J11	187.53	1.98	3.24	2.76	2.00
J12	190.74	1.64	3.66	3.18	1.88

Pollytag (159.75 – 185.02 g) retain total chlorine in the limits of 1.58 – 3.78 ppm. *Ceski* (181.97 – 190.74 g) – 1.64 – 3.86 ppm. The research indicates that ceramzite *Pollytag* has a chlorine retention efficiency about 16 %, meanwhile by ceramzite *Ceski* retention efficiency is 18 %. These results show that outdoor covers retain residual chlorine partially. Ceramzite *Leca* reached 76 % retention efficiency and could be recommended to use in green infrastructure as drainage layer.

3.2. Raised garden bed

Field experiments in raised garden bed aimed to analyze plants abillities to retain residual chlorine are presented in Table 7. Test samples were first semi quantitatively measured by X-ray fluorescence spectrometry (XRF) with a detection limit of approximately 10 µg/g.

Table 7. Plants research results on residual chlorine .

Sample	Cl ppm	K ppm	Ca ppm	Cr ppm	Fe ppm	Cu ppm	Zn ppm
Test sample TP1	<LOD	2670.73	56467.4	<LOD	932.56	13.77	82.27
Test sample TP2	<LOD	12050.57	51332	<LOD	682.25	<LOD	19.33
Test sample TP3	<LOD	12104.38	52326.03	<LOD	1505.58	16.23	7.75

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Test sample PS1	<LOD	2821.07	62694.84	<LOD	985.75	34.03	9.08	
Test sample PS2	<LOD	65893.4	27297.06	37.64	156.91	18.89	71.79	
Sample after watering	<LOD	75360.3	15043.22	<LOD	<LOD	<LOD	25.00	
Sample TP	<LOD	3072.12	48768.43	75.59	885.89	<LOD	36.3	
Sample PS	<LOD	3465.48	48259.56	71.6	986.89	21.58	36.14	
Test sample TP after watering	<LOD	22829.43	62847.73	<LOD	<LOD	<LOD	32.52	
Test sample ceramzite TP (693 g)	<LOD	35446.31	36728.77	67.73	54119.77	49.07	2291.	68
Test sample ceramzite PS (459 g)	<LOD	36193.05	38863.56	68.5	58878.71	59.47	2569.	19
Test sample 1TP (121g)	<LOD	3570.53	62603.3	<LOD	1502.04	16.5	12.00	
Test sample 1PS (100 g)	<LOD	4314.92	58666.03	<LOD	1264.57	20.77	11.12	

Table 7 presents the results obtained by testing the plants (*Tagetes patula ir Pisum savitum*) watered by sodium hypochlorite solution and by analysing GI layers applied in the construction (filtering layer; drainage layer). Reseach have determined residual chlorine values of test samples below the detection limit. It is assumed the experiment's results were caused by plants properties to evaporate chlorine through their vegetation system. These results are explained by the plants ability to survive in stressful conditions because of their capacities to limit the entry of toxic ions into the cells [47]. During the experiment have been not detected any harmful effects of residual chlorine (changes of plant growth, plants color, leaves size and etc.) on selected plants. It has showed that residual chlorine has worked as a useful microelement for plant nutrition. Studies highlight that in some cases the low concentrations of micropollutants migth have a positive impact on plants, but higher doses raise a harmfull effect [48]. The raised bed test using plants to reduce stormwater pollution by chlorine was preliminary experiment to analyze the phytoremediation capacities of plants to retain residual chlorine. The field experiments need to be continued in order to verify the obtained results and to evaluate the plants efficiency to reduce chlorine concentrations.

4. Conclusions

In order to achieve sustainable stormwater managament as well the Green Deal and and Circular Economy goals, the use of low cost and recyclable materials and plants are recommend in stormwater treatment affected by chlorine based disinfectants. Research revealed stormwater treatment efficiency depends on the type of filter material as well ceramzite type and plants species.

Experiments determined residual chlorine impact on stormwater indicators (pH, conductivity turbidity, color). pH medium value before filtration is 6.92 meanwhile after filtration obtained medium value is 7.46, conductivity medium value before filtration is 92.6 µs/cm, after filtration - 189.4 µs/cm, as well turbidity medium value before filtration is 0.15 NTU after filtration - 0.21 NTU. The changes of stormwater indicators might be influenced by these factors: the contact between test water sample and filter material as well type of filter material.

Experiments show filtration efficiency depend on various factors: type of filter material, concentrations of chlorine based disinfectants, solution acidity, contact time between filter material and polluted stormwater. Column and batch tests research resulted the efficiency of wood chips, saw dust and ceramzite to retain chlorine. The sawdust efficiency to remove chlorine from stormwater reaches approximately 96%, ceramzite *Leca* efficiency is approximately 76 %.

Difference in findings can be caused by climatic conditions, contact time between filter material and polluted stormwater, etc. Therefore, it is necessary to continue the experimental research in field conditions.

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