www.gi.sanu.ac.rs, www.doiserbia.nb.rs
J. Geogr. Inst. Cvijic. 2025, 75(2), pp. 183–198

Original scientific paper

UDC: 502.1:556.51(470.5)
https://doi.org/10.2298/IJGI241129007N

Received: November 29, 2024
Reviewed: January 25, 2025
Accepted: April 17, 2025

FALLEN LEAVES AS A POSSIBLE DECISION TO IMPROVE SURFACE WATER BODIES' QUALITY IN BELAYA RIVER BASIN (RUSSIA)

Elina Nasyrova[1]*, *Nikita Kalsin*[1], *Elvira Nafikova*[1], *Angelina Chashnikova*[1]

[1]Ufa University of Science and Technology, Department of Production Safety and Industrial Ecology, Ufa, Russia; e-mails: ElinaSagitovna@yandex.ru; kalsin.nikita@bk.ru; nafikova.ev@ugatu.su; mayerange20@gmail.com

Abstract: Currently, human activities significantly contribute to water pollution of natural water bodies. Pollution of water bodies with oil and petroleum products, especially in an urbanized area, is caused by the discharge of wastewater containing these products, as well as by oil leaks and emergencies. Similar pollution is typical for the water bodies in the basin of the Belaya River (Bashkortostan Republic, Russia), which is considered in this work. Bibliometric analysis by using VOSviewer revealed that pollution of water bodies is associated with crude oil pollution. For the remediation of water from crude oil, natural materials are widely used, including the sorbent from fallen leaves. Trees in cities produce a significant volume of fallen leaves every fall, which become plant waste. During the transition of the world community to a circular economy, fallen leaves should be considered as a material for obtaining a biosorbent. Five fraction sizes of *Acer platanoides* were studied to determine crude oil absorption. It has been established that particles with a size from one to two millimeters have the largest sorption capacity (5.41–5.77 g/g). Fallen leaves of *Acer platanoides* are capable of absorbing crude oil and can be recommended for treating polluted water from crude oil and petroleum products. The obtained proof of the ability of *Acer platanoides* leaves to absorb oil with their high buoyancy can be used in further studies of oil sorption process from water and the interaction of sorbent with oil in an aqueous medium under static and dynamic conditions.

Keywords: polluted water body; crude oil; *Acer platanoides*; fallen leaves; Belaya River

1. Introduction

In cities, due to the impact of anthropogenic factors, there is a water quality deterioration of water bodies (Chawla et al., 2024; Nasyrova et al., 2019). Industrial processes, agricultural practices, mining operations, and oil spills significantly contribute to water pollution by releasing toxic chemicals, heavy metals, organic compounds, and oil (Wu et al., 2024). Pollution of water bodies with oil and petroleum products could be caused by the discharge of wastewater containing these pollutants or by oil spill in emergencies (Bhattacharjee & Dutta, 2022). Crude oil pollution of water bodies is a worldwide problem (Osadebe et al., 2024).

Adsorption is one of the most effective and economical approaches to handle pollutants in the water (Ukhurebor et al., 2024). To remediate water from oil, natural materials are widely used (Oliveira et al., 2021; Zamparas et al., 2020). Sorbents from biomaterials are

*Corresponding author, e-mail: ElinaSagitovna@yandex.ru

environmentally friendly, biodegradable, and low-cost (Odunlami et al., 2022). For example, the plant leaves are considered as a sorption material due to their low cost and availability all year round (Adeniyi & Ighalo, 2019). In addition, the structure of biosorbents obtained from leaves is a cellular structure capable of adsorbing pollutants, including crude oil and petroleum products (Ighalo & Adeniyi, 2020).

Periodic leaves shedding accompany the biological process of tree growth. Trees in cities produce a significant volume of fallen leaves every fall (Cao et al., 2024). In the temperate climate zone, this happens in fall. In the forest environment, leaf litter is involved in the biological cycle – it is utilized by soil organisms and serves as a material for soil formation, since it contains all the necessary chemical elements. However, in the cities, fallen leaves (or dead leaves) become plant waste (Hobbie et al., 2014; Vargas-Soplín et al., 2024). They are mostly equated to solid municipal waste and taken to landfills (de Meira et al., 2024). However, currently there are methods for processing fallen leaves with the extraction of their useful properties (Blasques et al., 2024; Chanthavong et al., 2024). In recent years, sorption materials based on fallen leaves have successfully been used for removing pollutants contained in natural and wastewater.

Thus, the goal of this work is to propose a new application for fallen leaves, which are considered as plant waste in cities. Fallen leaves will be analyzed as a possible eco-friendly decision to improve the quality of urban water bodies contaminated with oil and petroleum products. Oil sorption capacity was assessed on the example of *Acer platanoides* fallen leaves collected on the Ufa city territory (Bashkortostan Republic, Russia). It should be noted that researchers from the neighboring region (Tatarstan Republic, Russia) conducted similar studies. Alekseeva et al. (2019) investigated the oil sorption capacity of modified mixed leaf litter, but not *Acer platanoides* as a separate species, which is widespread in Russia.

2. Methods and materials

2.1. Methods

Bibliometric analysis included data search with the use of Publish or Perish (PoP) 8 application, data mapping with the use of the VOSviewer version 1.6.20 application, and data analysis from VOSviewer mapping. In this study were used the keywords "oil polluted water bodies", "fallen leaves and oil polluted water bodies" in the Crossref database to obtain appropriate literature in the period of 1888–2024. According to the results of the analysis, about 1,000 articles were published. In the VOSviewer application, was conducted a co-occurrence analysis with keywords to visualize the results.

For laboratory analysis in the autumn of 2023 *Acer platanoides* leaf litter was collected on the territory of Ufa city. After collecting, the leaves were dried at room temperature. Further, they were crushed and sieved into fractions in a laboratory mill: large (≥ 5.0 mm), medium (1.0–2.0 mm) and small (.1–.5 mm). In order to determine the characteristics of the fallen leaves surface scanning electron microscopy (SEM) was used. SEM analysis was carried out with a JSM-649 OLV microscope at 300×, 500×, 1000×, and 2000× magnifications.

For analyzing sorption properties crude oil was considered as a pollutant. Sorption capacity studies were conducted in accordance with ASTM-F0726-17R24 Standard (ASTM International, 2024). The standard describes the types of adsorbents, oils with a range of viscosities and densities. Depending on the type of the adsorbent, the procedure of oil adsorption short test (15 min ± 20 s) was selected. For fallen leaves, the test was performed at 23 ± 4 °C on the adsorbent sample with minimum weight of 4 g. For analyzing the obtained experimental data of oil sorption capacity, MS Excel was used.

2.2. Study area

The study was conducted in the Ufa city (latitude: 54°44'35"N, longitude: 55°58'04"E), the capital of Bashkortostan Republic, Russia. Its location is shown in Figure 1 below.

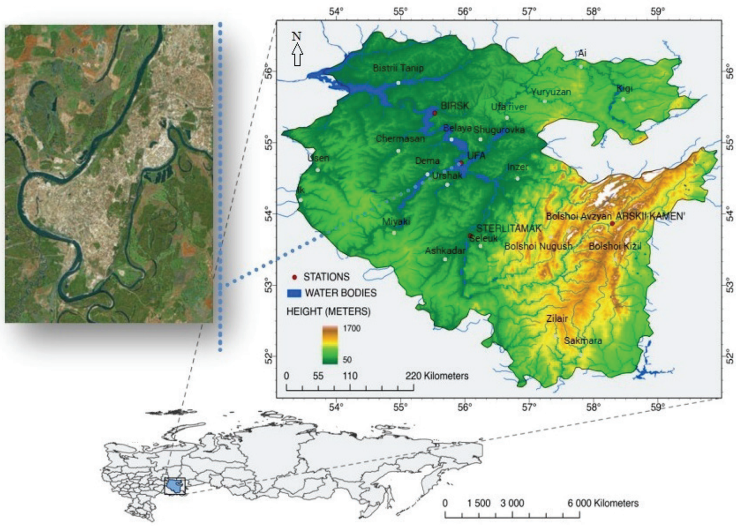

Figure. 1. Ufa city, Russia.
Note. Adapted from "Ocenka effektivnosti stohasticheskih modelej dlya prognozirovaniya gidrologicheskih harakteristik reki Belaya" [Assessment of the effectiveness of stochastic models for forecasting hydrological characteristics of the river Belaya], by D. A. Tarakanov, A. N. Elizariev, and I. A. Khasanov, 2023, *The North Caucasus Ecological Herald*, 19(4), p. 24. In the public domain.

The territory of the Bashkortostan Republic is located within the basins of the Volga, Ural and Ob rivers. There are about 13,000 rivers with a total length of over 57,000 km. The main part of them are rivers with a length of less than 100 km (Ministry of Nature Management and Ecology of the Republic of Bashkortostan, 2024). Ufa city is located in the east of the Russian plain in the interfluve of the Belaya, Ufa and Dema rivers within the Pribel hilly-uvalisty plain. The territory of Ufa is located in the northern forest-steppe subzone of the temperate zone. The main part of the Ufa city is located within the Belsko-Ufa watershed plain, which is dissected by a ravine network of erosive karst origin, as well as the valleys of the Shugurovka (in the north) and Sutoloka (in the southern part of the city) rivers flowing parallel to the Belaya and Ufa rivers from north to south. The natural hydrographic network within the territory of Ufa city has 90 water bodies of natural and artificial origin with an area of .1 ha to 84.0 ha (Nasyrova et al., 2019). The dynamics of water use from water bodies for various needs is presented in Table 1 and water discharge in Table 2 (Ministry of Nature Management and Ecology of the Republic of Bashkortostan, 2024).

Table 1. Dynamics of water use in the Bashkortostan Republic (million m^3)

Indicator	2017	2018	2019	2020	2021	2022	2023
Fresh water taken away	804.85	808.02	831.90	723.70	732.98	791.65	799.68
Used water, including for:	749.62	752.9	759.22	656.90	669.00	739.55	739.75
industrial needs	382.93	390.89	419.09	391.54	401.29	409.24	404.98

Table 1. Dynamics of water use in the Bashkortostan Republic (million m^3) (*continued*)

Indicator	2017	2018	2019	2020	2021	2022	2023
household and drinking needs	185.52	177.82	172.35	164.47	166.74	164.15	166.88
irrigation	4.38	4.62	4.67	2.70	2.30	1.66	3.53
agricultural water supply	6.75	6.13	5.29	4.73	4.56	3.96	3.82

Note. Data are from *Gosudarstvennyj doklad o sostojanii prirodnyh resursov i okružajušej sredy Respubliki Baškortostan v 2023 godu* [State report on the condition of natural resources and the environment of the Republic of Bashkortostan in 2023], by Ministry of Nature Management and Ecology Republic of Bashkortostan, 2024. https://ecology.bashkortostan.ru/upload/uf/14a/sufqis5j5kt409lhpihta87eiyjtjrfa/Gosdoklad_2024-.pdf. In the public domain.

According to Table 1, three periods were highlighted in the dynamics of the total fresh water use:

- 2017–2019, characterized by an increasing trend of water use;
- 2020, characterized by a 13% decrease in water use relative to 2019; it can be assumed that it was due to the COVID-19 pandemic, which affected all the sectors of the economy;
- 2021–2023, also characterized by a gradually increasing trend of water use.

The use of fresh water for industrial, household and drinking needs has similar trends.

Table 2. Dynamics of water discharge into surface water bodies of the Bashkortostan Republic (million m^3)

Indicator	2017	2018	2019	2020	2021	2022	2023
Total water discharge, including:	432.68	438.54	450.29	431.43	425.56	433.10	426.24
standard clean (without cleaning)	151.49	140.63	162.52	156.25	155.57	160.06	150.94
normatively cleaned	21.21	54.58	51.75	65.42	63.70	73.32	105.28
Polluted, including:	259.98	243.33	236.02	209.77	206.54	199.72	170.02
without cleaning	.15	.06	.06	0	.002	.00036	.00036
insufficiently cleaned	259.83	243.27	235.96	209.76	206.538	199.72	170.02

Note. Data are from *Gosudarstvennyj doklad o sostojanii prirodnyh resursov i okružajušej sredy Respubliki Baškortostan v 2023 godu* [State report on the condition of natural resources and the environment of the Republic of Bashkortostan in 2023], by Ministry of Nature Management and Ecology Republic of Bashkortostan, 2024. https://ecology.bashkortostan.ru/upload/uf/14a/sufqis5j5kt409lhpihta87eiyjtjrfa/Gosdoklad_2024-.pdf. In the public domain.

According to Table 2, there is no interannual dependence in the dynamics of wastewater discharge, as in the case of fresh water use. At the same time, since 2017 year, an increasing trend of normally cleared water discharge and a decreasing trend of polluted water discharge were observed, which may be due to the introduction of modern wastewater treatment technologies. In 2023, within the Ufa city, 240.49 million m^3 of fresh water was taken away from natural water bodies; 204.16 million m^3 of wastewater was discharged and .028 million tones of pollutants were discharged (Ministry of Nature Management and Ecology of the Republic of Bashkortostan, 2024).

The forest cover of the Bashkortostan Republic is 39.9% (Ministry of Forestry of the Republic of Bashkortostan, 2018). Hardwoods in the forests of the Bashkortostan Republic are represented by 4 species: oak (high-stemmed and low-stemmed), elm, maple, and ash (Figure 2).

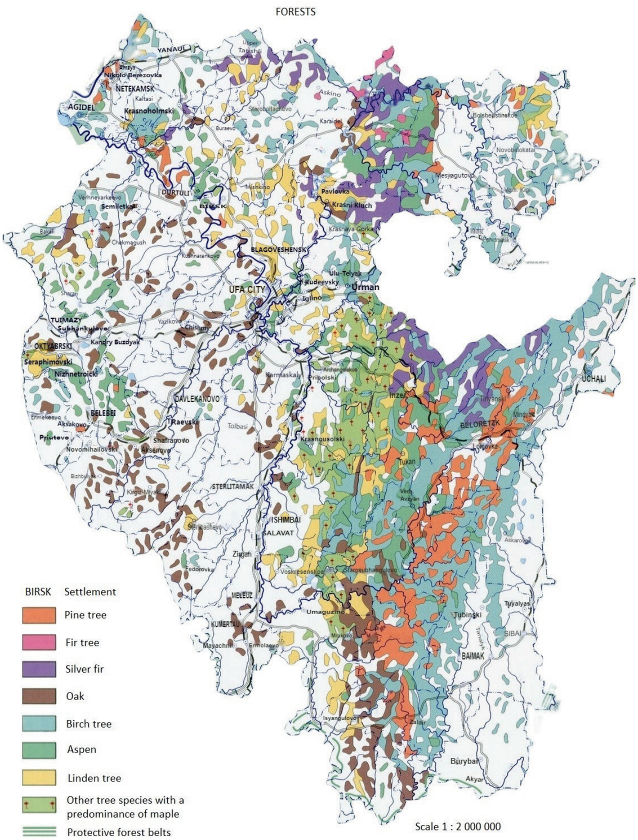

Figure 2. Distribution of tree species in the Bashkortostan Republic.
Note. Adapted from "Atlas respubliki Baškortostan" [Atlas of the Bashkortostan Republic], by I. M. Yaparov, 2005, https://rusneb.ru/catalog/000199_000009_010083288/. Copyright 2005 by Roskartografiya.

Oak is the most widespread among hardwoods, with an area share of 56.4%. The second place in distribution is occupied by maple, whose specific weight in the area is 33.7% (Ministry of Forestry of the Republic of Bashkortostan, 2018). In the forests, maple is represented by two species: *Acer negundo* and *Acer platanoides.* The following species are characteristic of the Ufa city green zone: *Quercus robur*, *Tilia cordata*, *Populus tremula*, and *Acer platanoides*. On the territory of Ufa city, law does not regulate the collection of fallen leaves. Every year, municipal services take them to landfills by collecting them in bags.

2.3. Pollution of water bodies in the study area

According to Table 1, most of the water from the natural water bodies of the study area is used for production needs. As Table 2 shows, some of the wastewater discharged into surface water bodies is insufficiently cleaned, which affects the quality of water bodies (Table 3; Ministry of Nature Management and Ecology of the Republic of Bashkortostan, 2024).

Table 3. Concentration of pollutants in the rivers of the Republic of Bashkortostan in 2023

River, place	Pollutant, mg/l							
	Fe	Oil products	Mn	Cu	SO_4^{2-}	NO^{3-}	NO_2^{3-}	NH_4
Bolshoi Avzyan	.6	.15	–	.002	<100	<9	<.02	
Bolshoi Nugush	.7	.15	–	.003	<100	<9	<.02	.8
Ashkadar	3.0	.15	.18	.003	100	<9	<.02	.4
Seleuk	2.6	.1	–	.003	<100	<9	<.02	.8
Inzer	.4	–	.11	.003	<100	–	<.02	<.4
Urshak in the alignment above d. Bulgakovo	.1	.05	.26	.003	1200	36	–	–
Urshak in the line d. Bulgakovo	.1	<.05	.27	.003	1200	36	.06	.4
Ufa, d. Verhnii Suyan	.6	–	.18	.002	100	18	<.02	<.4
Ufa, p. Karaidel	.2	–	.12	–	–	18	<.02	<.4
Ufa, p. Pavlovka	.2	–	.26	–	100	<9	<.02	<.4
Ufa, Ufa city	.3	–	.26	.003	800	<9	.02	<.4
Ai	.7	–	.22	.003	<100	–	<.02	–
Kigi	.5	–	.298	.004	100	18	<.02	<.4
Yuryuzan	.4	–	.11	.002	<100	<9	<.02	<.4
Shugurovka	.2	<.05	.24	.003	500	18	.06	–
Dema, s. Karmishevo	.5	–	–	.003	400	–	.02	<.4
Dema, Ufa city	.3	–	.16	.003	400	–	.08	<.4
Miyaki	2.1	–	–	.003	–	36	.02	<.4
Chermasan	.2	<.05	.2	.004	400	–	.04	–
Bistrii Tanip	.4	<.05	.298	.004	900	27	–	–
Ik, within the city Oktyabrskii	.2	–	.2	–	200	<9	<.02	.04
Ik, below the city Oktyabrskii	.3	–	.19	–	300	<9	< .02	.8
Usen, above the city Tuimazi	.2	–	.18	–	–	<9	<.02	.4
Usen, below the city Tuimazi	.2	–	.18	–	200	<9	<.02	.8
Bolshoi Kizil	.9	.15	–	.003	<100	<9	–	–
Sakmara	1.1	.15	–	.003	<100	<9	.02	<.4
Zilair	1.3	.1	–	.003	<100	<9	.02	.8
Belaya, in the alignment above Ufa city	.3	.05	.09	.003	300	18	.02	<.4
Belaya, Ufa city	.2	–	.09	.003	200	<9	.02	<.4

Note. Data are from *Gosudarstvennyj doklad o sostojanii prirodnyh resursov i okružajušej sredy Respubliki Baškortostan v 2023 godu* [State report on the condition of natural resources and the environment of the Republic of Bashkortostan in 2023], by Ministry of Nature Management and Ecology Republic of Bashkortostan, 2024. https://ecology.bashkortostan.ru/upload/uf/14a/sufqis5j5kt409lhpihta87eiyjtjrfa/Gosdoklad_2024-.pdf. In the public domain.

As it can be seen from Table 3, various pollutants, including petroleum products, are found in rivers. It should be noted that in some cases there are exceedances of the maximum permissible concentrations. For example, the maximum permissible concentration for petroleum products is .05 mg/l (Ministry of Agriculture of the Russian Federation, 2016). The water quality of water bodies within the Ufa city in 2023 year, according to the combinatorial index of water pollution, is (Hydrochemical Institute, 2023):

- Belaya, in the alignment above Ufa city—polluted water;
- Belaya, Ufa city—polluted water;
- Dema, Ufa city—polluted water;
- Ufa, Ufa city—polluted water;

- Shugurovka—dirty water.

Within the Ufa city, the dirtiest river is the Shugurovka. It is a small right-bank tributary of the Ufa river, flowing through the territory of the northern industrial zone of Ufa city. The water quality was affected by emergency discharges from housing and communal services enterprises and sewage from residential and industrial areas. Accordingly, the treatment of water bodies from pollutants is relevant for the study area.

2.4. Description of Acer platanoides

Acer platanoides is a woody plant widespread in Europe and Southwest Asia, a species of the genus *Acer* of the Sapindaceae family. It is a common plant in all regions of central Russia. The leaves contain organic acids (acetic, succinic, phthalic), polyisopropenes (squalene), rubber, carbohydrates, alkaloids, aldehydes (alpha-hexene, beta-hexene), carotenoids (alpha-carotene, beta-carotene, xanthophyll epoxide, etc.), vitamins C (up to 268 mg/%), E, phenolic carboxylic acids (salicylic, gallic), nitrogen-containing compounds (methylamine), tannins, flavonoids, anthocyanins (Natural Museum, n.d.). In its chemical composition, the leaf litter of *Acer platanoides* contains lignin, cellulose, and tannins, which contribute to the course of chemisorption processes involving functional groups in the composition of these biopolymers (Natural Museum, n.d.). These substances have a high potential as adsorbents.

3. Result and discussion

3.1. Research trends

Using VOSviewer, the bibliography was mapped by keywords "oil polluted water bodies" and five clusters were found (Figure 3). A different color indicates each cluster. Meanwhile, the variation in the frame size indicates the links' different strengths.

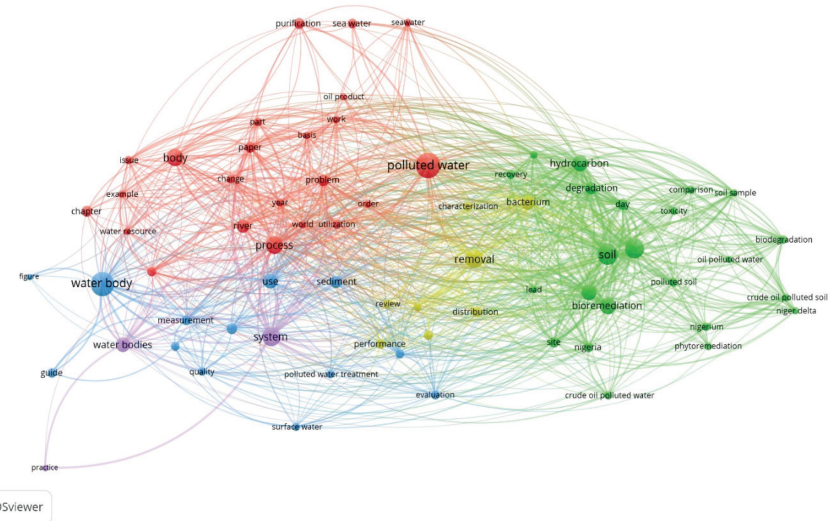

Figure 3. Network visualization of "oil polluted water bodies".

The clusters are:

- 1 (23 items/red), the dominant item—polluted water;
- 2 (23 items/green), the dominant item—soil;
- 3 (13 items/blue), the dominant item—mg/l;
- 4 (8 items/yellow), the dominant item—removal;
- 5 (3 items/ purple) the dominant item—system.

The analysis revealed that pollution of water bodies is associated with crude oil pollution. Using VOSviewer, the bibliography was mapped by keywords "fallen leaves and oil polluted water bodies" and six clusters were found (Figure 4).

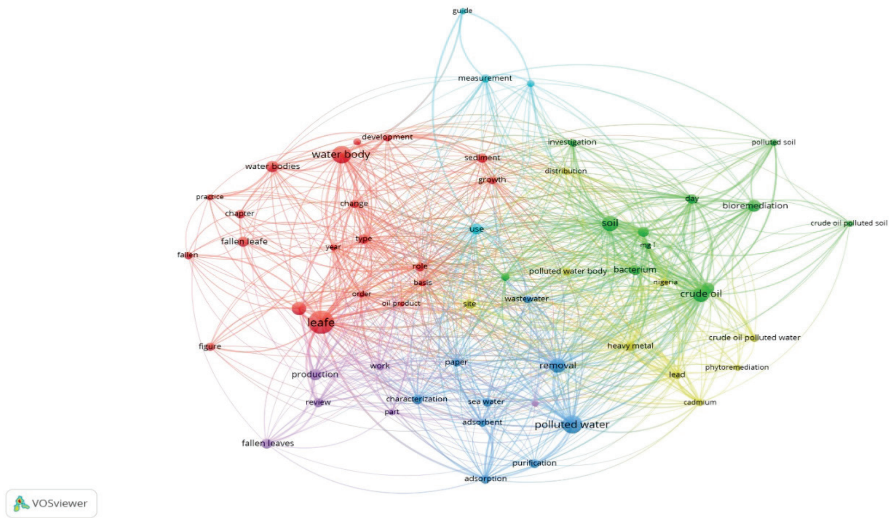

Figure 4. Network visualization of "fallen leaves and oil polluted water bodies".

The clusters are:

- 1 (20 items/red), the dominant item—leaf;
- 2 (12 items/green), the dominant item—crude oil;
- 3 (9 items/blue), the dominant item—removal;
- 4 (9 items/yellow), the dominant item—site;
- 5 (6 items/purple), the dominant item—review;
- 6 (4 items/ azure), the dominant item—measurement.

The analysis revealed that leaf is associated with crude oil and adsorption. Thus, this direction is relevant. The connection between the leaves and the soil contaminated with crude oil was also noticed. Scientists are also actively investigating the possibility of obtaining biochar from leaves for the oil-polluted lands remediation (Fedeli et al., 2024).

3.2. Investigation of Acer platanoides leaves sorption capacity

The study of *Acer platanoides* leaves sorption capacity was conducted in several stages. In the first stage, after collecting and natural drying of the leaves, their morphological structure was analyzed using a visual-instrumental method. For this purpose, five best samples were selected to describe the *Acer platanoides* leaves (Figure 5). The color of the leaves samples varied from dirty brown to golden yellow and dirty yellow.

Figure 5. *Acer platanoides* leaves.

The first two leaves distinguished by a large part of the spotting and the darkest shades. Spotting for this species is usually caused by the fungus pathogen *Rhytisma Acerinum*. The length of the maple leaf similarly decreases from 12.5 cm to 6 cm, the step size reaches 0.5–2.0 cm; width 6.5–15.0 cm, the step reaches 2–3 cm; the length of the petiole varies from 4.5 cm to 12 cm; the number of veins is 8–15 pieces.

In the second stage, the dried leaves were crushed and divided into fractions. The crushed mass of *Acer platanoides* leaf litter was divided into 6 fraction sizes: 5.0; 2.0; 1.0; .5; .25; and .1 mm (Figure 6).

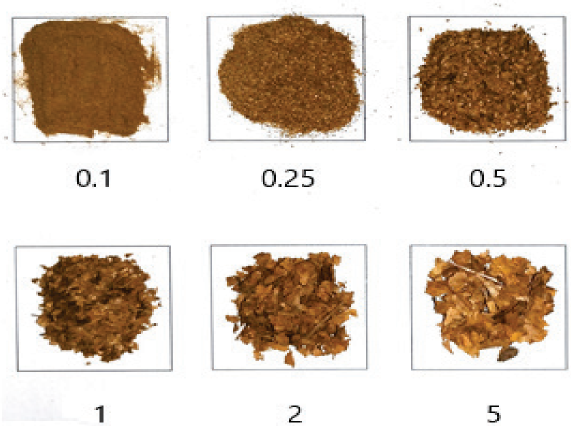

Figure 6. *Acer platanoides* crushed leaves by fractions (mm).

Based on the size of the fractions, three groups of particles were distinguished: large (≥ 5.0 mm), medium (1.0–2.0 mm), and small (.1–.5 mm). After crushing the leaves (100 g), the fractions were distributed according to the following composition: 5 mm—8.94%, 2 mm—44.97%, 1 mm—26.57%, .5 mm—11.18%, .25 mm—6.0%, and .1 mm—2.34%.

In the third stage, the structure of the fractions was studied with a microscope. Scanning electron microscopy images of the *Acer platanoides* leaves surface are shown in Figure 7.

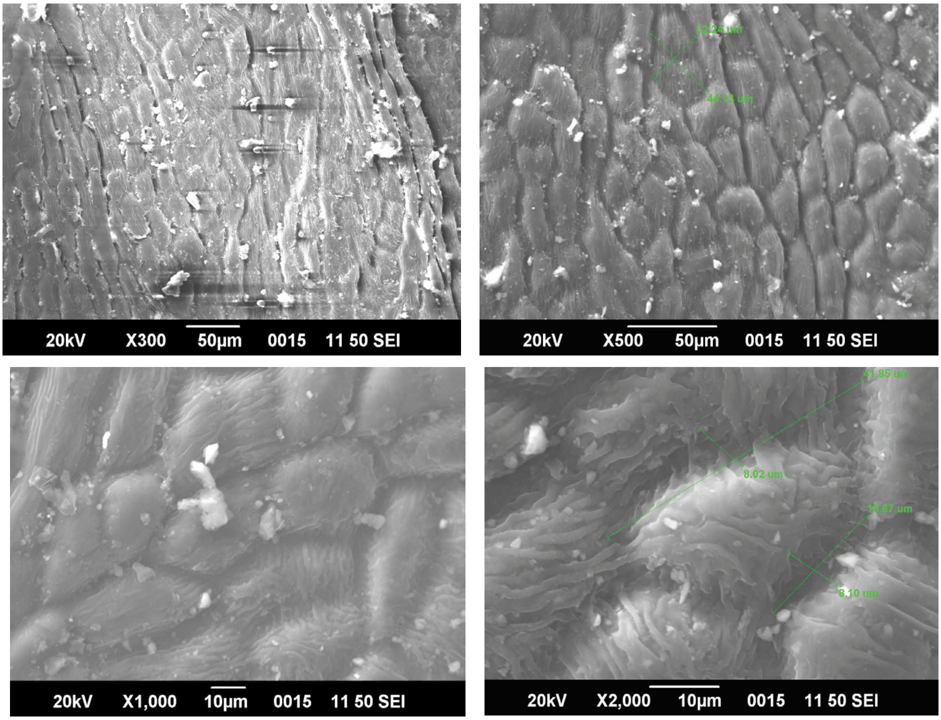

Figure 7. *Acer platanoides* SEM images.

The surface of *Acer platanoides* leaves is heterogeneous, with unevenness and different pores, which may provide a large number of adsorption sites. The main characteristics that determine the effectiveness of a sorbent are water absorption, buoyancy, and oil capacity. In this work, these properties of *Acer platanoides* leaves were analyzed.

Water absorption characterizes the efficiency of water absorption by the sorbent. To achieve greater oil absorption, water absorption should be as low as possible. Based on the work of Malyshkina (2020), there is a degree of water absorption: less than 1 g/g (low), 1–10 g/g (average), and more than 10 g/g (high). According to our results, the average water absorption for the investigated *Acer platanoides* leaves was 3.1–3.9 g/g.

Depending on the time that the sorbent can last on the surface of the water before the start of the immersion process in the lower layers, the sorbents of high buoyancy (more than 72 hours), limited buoyancy (3–72 hours), and non-floating (up to three hours) were distinguished (Malyshkina, 2020). At the next stage of this research, *Acer platanoides* crushed leaves buoyancy was studied for 72 hours. The sorbent from the *Acer platanoides* leaves was classified as a high floating sorbent (more than 72 hours). The *Acer platanoides* fractions colored an aqueous solution due to anthocyanins present in the chemical composition of the litter. Anthocyanins are one of the most common pigments in nature; they also have solubility in water and a high intensity of coloring.

Oil capacity is the mass of oil that a sorbent is able to absorb per gram of its mass. Oil capacity below 5 g/g is classified as low, 5–15 g/g—average, more than 15 g/g—high (Malyshkina, 2020). In this research fractions of *Acer platanoides* leaves were used to determine the oil capacity in static conditions. The results of oil capacity obtained in the work are shown in Figure 8.

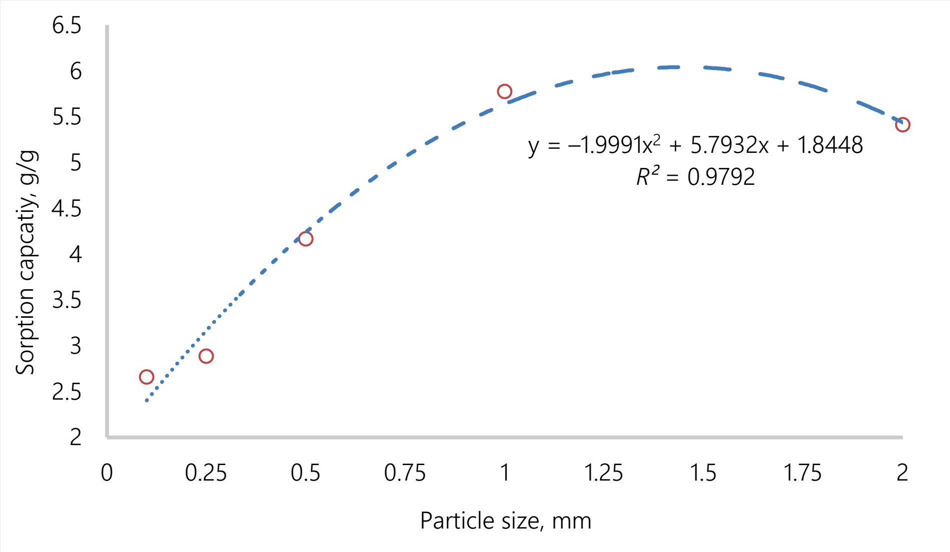

Figure 8. Sorption capacity of *Acer platanoides* by fractions.

For 5 mm fractions, the sorption capacity was 2.8 g/g and it is not represented graphically. Low sorption capacity was due to the predominance of leaf stems in this fraction. A correlation was revealed between the sorption capacity and the particle size of *Acer platanoides* leaves. On a Cheddock scale, with a coefficient R^2 = .9792, there is a high correlation between the parameters.

As it can be seen from Figure 8, particles with a size from 1 to 2 mm have the largest sorption capacity. It should be noted that after crushing the *Acer platanoides* fallen leaves, these fractions make up the largest part among the other sizes of fractions. However, sorption capacity of *Acer platanoides* is low (below 5 g/g). In this way, fallen leaves of *Acer platanoides* are capable of absorbing crude oil. They can be used for the treatment of water from crude oil and petroleum products.

3.3. Discussion

In this article, specific examples of research on the adsorption properties of leaves were considered. Akpomie and Conradie (2023) investigated the use of *Populus nigra* leaves for purifying the aquatic environment from vegetable oil. The sorption capacity was 2.382 g/g, and the possibility of reuse in the vegetable oils removal was determined. Alhajali et al. (2022) studied the possibility of removing nitrates and phosphates from the aquatic environment using *Pistacia lentiscus* leaf powder. The sorption capacity was .01006 g/g when removing nitrates and .00987 g/g when removing phosphates. Mosoarca et al. (2023) tested a sorbent from the *Asplenium scolopendrium* leaves when removing a crystalline purple dye from water. The highest calculated index of the adsorption capacity was .224 g/g. The most significant factor affecting the adsorption index was the pH. Subhashish et al. (2022) investigated the effectiveness of sorbents from the leaves of neem, Java palm, guava, sapota, cream apple, and mango trees in removing Fe from the aquatic environment. The collected leaves were washed with distilled water diluted with H_2SO_4, dried to a minimum moisture content, and ground to a powdery state. Mango leaves showed the greatest effectiveness, followed by guava leaves, neem leaves, Java palm leaves, sapota leaves, and cream apple leaves in order of decreasing effectiveness. Stepanova et al. (2013) evaluated the oil capacity of unmodified birch litter and modified with 1 N sulfuric acid solution at temperatures of 20 °C and 75 °C; modified with glacial acetic acid at temperatures of 20 °C and 75 °C under static and dynamic conditions. The best result was 14.31 g/g.

Researchers also study the sorption properties of maple leaves in their works. Amirnia et al. (2016) used *Acer saccharum* leaves and described continuous removal of Cu^{2+} ions from aqueous solutions in a column with a nozzle. Eight adsorption-desorption cycles with a regeneration efficiency of 98% using 0,1n H_2SO_4 were carried out in laboratory conditions. According to the obtained results, the metal concentration decreased from 15–110 mg/l to 1 mg/l, which corresponds to Canadian drinking water standards. The adsorption capacity of the *Acer saccharum* sorbent remained fairly constant and amounted to 18.3 g/g for eight cycles. This type of maple is also considered as an unconventional, cost-effective sorbent for the removal of Ni^{2+} from aquatic environment. It was found that the powder from the leaves has a high specific surface area (11.99 m^2/g) and contains binding functional groups Ni^{2+} (for example, hydroxyl and carboxyl). The maximum biosorption of Ni^{2+} was obtained at pH 4.0 (Ravuri & Gilbert, 2013).

A biosorbent prepared from *Acer oblongum* leaves was used for removing Cd^{2+} from wastewater. It was found that the optimal pH and dosage of the sorbent were 7.0 and 2.0 g/l, respectively, and the removal efficiency was 93.3% at an equilibrium removal time of 90 min. The achieved biosorption of Cd^{2+} on activated maple biomass was 0.044 g/g (Joshi et al., 2022). Vishwakarma et al. (2022) used dried activated *Acer oblongum* biomass for removing Pb^{2+} from synthetic wastewater. The maximum adsorption was recorded at an initial concentration of metal ions of 10 mg/l, a dose of the biosorbent of 2.5 g, pH = 5 and a contact time of 105 minutes for activated biomass. Silajcheva et al. (2015) used the leaves of *Acer platanoides L.* as a sorption material for removing Fe^{2+} ions from water. The maximum sorption capacity at a temperature of 97 °C was 9.593 mg/g. The available works in this area and analyzed in this article showed that maple leaves have already been investigated as a possible decision for the absorption of pollutants such as Cu^{2+}, Ni^{2+}, Cd^{2+} and Pb^{2+}.

However, the oil sorption capacity of maple leaves alone is poorly studied. For example, in the work of Alekseeva et al. (2019) the oil capacity of modified mixed leaf litter was studied. The mixed leaf litter contained fallen leaves of birch (35%), poplar (31%), linden (10%), maple (10%), and other types of trees (14%). At the same time, the oil capacity varied from 6.56 to 12.13 g/g depending on the time from 1 to 60 minutes, respectively. However, the sorption oil capacity of *Acer platanoides* leaves was not studied separately.

The authors considered fallen maple leaves as a plant sorbent (biosorbent) used to absorb petroleum products. The presented study introduces a decision to improve surface water bodies' quality. Other authors actively consider sorbents as a possible decision for water treatment. For example, Osman et al. (2023) analyzed different types of biosorbents used for water treatment. Iakovleva and Sillanpää (2020) showed that some low-cost materials and industrial by-products could be used as adsorbents for wastewaters. Tran et al. (2015) considered low-cost biosorbents obtained from lignocellulose for specific organic pollutants adsorption.

On the other hand, considering fallen leaves as a plant sorbent, it is important to focus on the particle size. The analysis of the works showed that sorption capacity of fallen leaves at different sizes of fractions (after grinding) has not been studied sufficiently. The results obtained in this work show that there is a dependence between the sorption capacity and the particle size of crushed fallen leaves of *Acer platanoides*.

5. Conclusion

Pollution of water bodies in the Belaya River basin by oil and petroleum products occurs due to the presence of these pollutants in wastewater. Pollution is also possible due to an oil spill in an emergency. Sorbents can be used to purify water in both ways of contamination. For example, by using an adsorber device in an industrial plant to purify polluted waters. In case of an oil spill on the water surface, first, booms are used to localize the spill and then the sorbents for oil collection.

Plant waste, namely fallen leaves in the city, is a valuable resource and can be used for various purposes, from obtaining fertilizers to making paper. In addition, during the transition of the world community to a circular economy, fallen leaves should be considered as a material for obtaining a biosorbent. The works analyzed in this article showed that maple leaves have already been investigated as a possible decision for the absorption of pollutants such as Cu^{2+}, Ni^{2+}, Cd^{2+} and Pb^{2+}. However, the oil sorption capacity of maple leaves alone is poorly studied.

The paper analyzes fallen leaves of *Acer platanoides* collected on the urbanized territory of Ufa city. For the analysis, the leaves were crushed into six fraction sizes. It has been established that particles with a size from 1 to 2 mm have the largest sorption capacity, 5.41–5.77 g/g (average oil capacity). Fallen leaves of *Acer platanoides* are capable of absorbing crude oil and recommended for treatment of polluted water from crude oil and petroleum products. They can be used in adsorber devices or when eliminating an oil spill on the water surface, as they have high buoyancy (more than 72 hours).

The authors point out that this study has some limitations: fallen leaves were used without modifications, except for drying and grinding. Accordingly, with modifications, an increase in oil sorption capacity is possible. In this work, the sorption of petroleum products from water was not evaluated. It is in the plans for further research. Also, in the perspective of developing this work, the study of other tree species growing in the Ufa city and the Bashkortostan Republic is planned, as well as changing the structure of sorbents by creating granules and pillows.

Since maple leaves are capable of absorbing both heavy metals and petroleum products, it is interesting for further research to study the simultaneous absorption of these pollutants by the leaves. On the other hand, maple leaves release certain chemicals (anthocyanins) in contact with water, and therefore it is interesting to study possible chemical reactions between pollutants and anthocyanins that occur in the aquatic environment.

Acknowledgements

Authors are grateful to the personnel of the Research Equipment Sharing Center "Nanotech" of Ufa University of Science and Technology for their assistance with instrumental analysis.

References

Adeniyi, A. G., & Ighalo, J. O. (2019). Biosorption of pollutants by plant leaves: an empirical review. *Journal of Environmental Chemical Engineering, 7*(3), Article 103100. https://doi.org/10.1016/j.jece.2019.103100

Akpomie, K. G., & Conradie, J. (2023). Batch sorption of vegetable oil from simulated oil-polluted water onto Populus nigra leaf waste. *International Journal of Environmental Science and Technology, 20*(5), 5377–5390. https://doi.org/10.1007/s13762-022-04328-z

Alekseeva, A. A., & Stepanova, S. V. (2019). Effect of Plasma Surface Modification of Mixed Leaf Litter on the Mechanism of Oil Film Removal from Water Bodies. *Russian Journal of General Chemistry, 89*(13), 2763–2768. https://doi.org/10.1134/S107036321913005X

Alhajali, O., Ali-Nizam, A., & Almostafa, R. (2022). Application of Pistacia atlantica Leaves Powder as Natural Material To Remove Nitrate and Phosphate Ions From Domestic Wastewater by Characterization, Bio-removal, and Phytotoxicity Studies. *Journal of the Turkish Chemical Society Section A: Chemistry, 9*(3), 759–776. https://doi.org/10.18596/jotcsa.1026262

Amirnia, S., Ray, M. B., & Margaritis, A. (2016). Copper ion removal by Acer saccharum leaves in a regenerable continuous-flow column. *Chemical Engineering Journal, 287*, 755–764. https://doi.org/10.1016/j.cej.2015.11.056

ASTM International. (2024). *Standard Test Method for Sorbent Performance of Adsorbents for use on Crude Oil and Related Spills (ASTM-F0726-17R24).* ASTM International. https://doi.org/10.1520/F0726-17

Bhattacharjee, S., & Dutta, T. (2022). An overview of oil pollution and oil-spilling incidents. In P. Das, S. Manna, & J. K. Pandey (Eds.), *Advances in Oil-Water Separation – A Complete Guide for Physical, Chemical, and Biochemical Processes* (pp. 3–15). Elsevier Inc. https://doi.org/10.1016/B978-0-323-89978-9.00014-8

Blasques, R. V., Camargo, J. R., Veloso, W. B., Meloni, G. N., Fernandes, F. A., Germinare, B. F., Guterres e Silva, L. R. G., de Siervo, A., Paixao, T. R. L. C., & Janegitz, B. C. (2024). Green Fabrication and Analytical Application of Disposable Carbon Electrodes Made from Fallen Tree Leaves Using a CO_2 Laser. *ACS Sustainable Chemistry & Engineering, 12*(8), 3061–3072. https://doi.org/10.1021/acssuschemeng.3c06526

Cao, Y., Li, X., Li, Y., Guo, J., & Qi, Y. (2024). Quantification and Proxy Indicators of the Carbon Pool in Urban Tree Litterfall: A Case Study of Urban Green Spaces in Beijing. *Forests*, *15*(1), Article 144. https://doi.org/10.3390/f15010144

Chanthavong, V., Prabhakar, M. N., Lee, D. W., & Song, J.-I. (2024). Extraction of Cellulose Microfibers From Waste Fallen Dried Leaves and Fabrication of a Degradable Composite Film for Packaging Applications. *Journal of Inorganic and Organometallic Polymers and Materials, 34*(4), 1861–1875. https://doi.org/10.1007/s10904-023-02928-x

Chawla, H., Singh, S. K., & Haritash, A. K. (2024). Reversing the damage: ecological restoration of polluted water bodies affected by pollutants due to anthropogenic activities. *Environmental Science and Pollution Research, 31*(1), 127–143. https://doi.org/10.1007/s11356-023-31295-w

de Meira, A. M., Nolasco, A. M., de Souza, E. C., de Souza, M. P., Pereira, A. K. S. P., Ucella-Filho, J. G. M., & Dias Júnior, A. F. (2024). Integrated municipal management of waste from tree pruning and removal. *Urban Forestry & Urban Greening, 94*, Article 128238. https://doi.org/10.1016/j.ufug.2024.128238

Fedeli, R., Celletti, S., Alexandrov, D., Nafikova, E., & Loppi, S. (2024). Biochar-mediated bioremediation: A sustainable strategy to increase Avena sativa L. tolerance to crude oil soil contamination. *Environmental Science and Pollution Research, 31*(40), 52774–52783. https://doi.org/10.1007/s11356-024-34732-6

Hobbie, S. E., Baker, L. A., Buyarski, C., Nidzgorski, D., & Finlay, J. C. (2014). Decomposition of tree leaf litter on pavement: implications for urban water quality. *Urban Ecosystems, 17*(2), 369–385. https://doi.org/10.1007/s11252-013-0329-9

Hydrochemical Institute. (2023). *Surface water quality of the Russian Federation*. https://gidrohim.com/node/61

Iakovleva, E., & Sillanpää, M. (2020). Novel sorbents from low-cost materials for water treatment. In M. Sillanpää (Ed.), *Advanced Water Treatment: Adsorption* (pp. 265–359). Elsevier Inc. https://doi.org/10.1016/B978-0-12-819216-0.00004-7

Ighalo, J. O., & Adeniyi, A. G. (2020). A mini-review of the morphological properties of biosorbents derived from plant leaves. *SN Applied Sciences, 2*(3), Article 509. https://doi.org/10.1007/s42452-020-2335-x

Joshi, H. K., Vishwakarma, M. C., Kumar, R., Sharma, H., Joshi, S. K., & Bhandari, N. S. (2022). Adsorption of Cd^{2+} from synthetic wastewater by modified leaves of *Eupatorium adenophorum* and *Acer oblongum*: thermodynamics, kinetics and equilibrium studies. *Discover Water, 2*(1), Article 9. https://doi.org/10.1007/s43832-022-00018-6

Malyshkina, E. S. (2020). Classification of sorbents used in technologies for purification of waste water from petroleum products. *Urban Construction and Architecture, 10*(3), 26–34. https://doi.org/10.17673/Vestnik.2020.03.5

Ministry of Agriculture of the Russian Federation. (2016). Normativy kachestva vody vodnyh obektov rybohozyajstvennogo znacheniya, v tom chisle normativov predelno dopustimyh koncentracij vrednyh veshchestv v vodah vodnyh obektov rybohozyajstvennogo znacheniya, prikaz N 552 [Water quality standards for water bodies of fisheries importance, including standards for maximum permissible concentrations of harmful substances in the waters of water bodies of fisheries importance, Order № 552]. https://base.garant.ru/71586774/

Ministry of Forestry of the Republic of Bashkortostan. (2018). *Lesnoj plan Respubliki Baškortostan 2019–2028* [Forest plan of the Republic of Bashkortostan 2019–2028]. https://npa.bashkortostan.ru/22833/

Ministry of Nature Management and Ecology of the Republic of Bashkortostan. (2024). *Gosudarstvennyj doklad o sostojanii prirodnyh resursov i okružajuŝej sredy Respubliki Baškortostan v 2023 godu* [State report on the condition of natural resources and the environment of the Republic of Bashkortostan in 2023. https://ecology.bashkortostan.ru/upload/uf/14a/sufqis5j5kt409lhpihta87eiyjtjrfa/Gosdoklad_2024-.pdf

Mosoarca, G., Vancea, C., Popa, S., Dan, M., & Boran, S. (2023). Utilizing Novel Lignocellulosic Material from Hart's-Tongue Fern (*Asplenium scolopendrium*) Leaves for Crystal Violet Adsorption: Characterization, Application, and Optimization. *Polymers, 1*5(19), Article 3923. https://doi.org/10.3390/polym15193923

Nasyrova, E., Elizaryev, A., Aksenov, S., Baiduk, Y., Kamaeva, E., & Akhtyamov, R. (2019). Geoenvironmental assessment of urban water bodies. *E3S Web of Conferences, 110*, Article 02045. https://doi.org/10.1051/e3sconf/201911002045

Natural Museum. (n.d.). *Description of Acer platanoides*. Retrieved November 28, 2024 from https://natural-museum.ru/flora/клен-остролистный

Odunlami, O. A., Odiakaose, E. O., Owoicho, I. A., Oladimeji, T. E., & Elehinafe, F. B. (2022). Treatment of oil spills with natural sorbents: a review. *International Journal of Recent Research in Physics and Chemical Sciences, 9*(1), 16–25. https://doi.org/10.5281/zenodo.6586925

Oliveira, L. M. T. M., Saleem, J., Bazargan, A., Duarte, J. L. S., McKay, G., & Meili, L. (2021). Sorption as a rapidly response for oil spill accidents: a material and mechanistic approach. *Journal of Hazardous Materials, 407*, Article 124842. https://doi.org/10.1016/j.jhazmat.2020.124842

Osadebe, A. U., Ogugbue, C. J., & Okpokwasili, G. C. (2024). Bioremediation of crude oil polluted surface water using specialised alginate-based nanocomposite beads loaded with hydrocarbon-degrading bacteria and inorganic nutrients. *Bioremediation Journal*, 1–23. https://doi.org/10.1080/10889868.2024.2381022

Osman, A. I., El-Monaem, E. M. A., Elgarahy, A. M., Aniagor, C. O., Hosny, M., Farghali, M., Rashad, E., Ejimofor, M. I., López-Maldonado, E. A., Ihara, I., Yap, P-S., Rooney, D. W., & Eltaweil, A. S. (2023). Methods to prepare biosorbents and magnetic sorbents for water treatment: a review. *Environmental Chemistry Letters, 21*(4), 2337–2398. https://doi.org/10.1007/s10311-023-01603-4

Ravuri, D., & Gilbert, W. (2013). Biosorption of Ni (II) from aqueous solution using Acer saccharum leaves (ASL) as a potential sorbent. *International Journal of Advanced Chemistry, 2*(1), 1–5. https://doi.org/10.14419/ijac.v2i1.1531

Silajcheva, M. V., Stepanova, S. V., & Shajhiev, I. G. (2015). Kinetika sorbcii ionov zheleza (II) klenovym opadom [Kinetics of sorption of iron (II) ions by maple leaf litter]. *Bulletin of Kazan Technological University*, *18*(20), 257–259. https://elibrary.ru/download/elibrary_25036255_67178017.pdf

Stepanova, S. V., Shajmardanova, A. Sh., & Shajhiev, I. G. (2013). Opad berezy i ee himicheskie modifikaty dlya udaleniya nefti [Birch litter and its chemical modifiers for oil removal]. *Bulletin of Kazan Technological University*, *16*(14), 215–217. https://cyberleninka.ru/article/n/opad-berezy-i-ee-himicheskie-modifikaty-dlya-udaleniya-nefti

Subhashish, D., Naga, S. A. K., Veerendra, G. T. N., & Arunchaitanya, S. (2022). The removal of iron from synthetic water by the applications of plants leaf biosorbents. *Cleaner Engineering and Technology*, *9*, Article 100530. https://doi.org/10.1016/j.clet.2022.100530

Tarakanov, D. A., Elizariev, A. N., & Khasanov, I. A. (2023). Ocenka effektivnosti stohasticheskih modelej dlya prognozirovaniya gidrologicheskih harakteristik reki Belaya [Assessment of the effectiveness of stochastic models for forecasting hydrological characteristics of the river Belaya]. *The North Caucasus Ecological Herald*, *19*(4), 23–29. http://ecokavkaz.ru/media/docs/2023/4/19-4-9.pdf

Tran, V. S., Ngo, H. H., Guo, W., Zhang, J., Liang, S., Ton-That, C., & Zhang, X. (2015). Typical low cost biosorbents for adsorptive removal of specific organic pollutants from water. *Bioresource Technology*, *182*, 353–363. https://doi.org/10.1016/j.biortech.2015.02.003

Ukhurebor, K. E., Hossain, I., Pal, K., Jokthan, G., Osang, F., Ebrima, F., & Katal, D. (2024). Applications and Contemporary Issues with Adsorption for Water Monitoring and Remediation: A Facile Review. *Topics in Catalysis*, *67*(1), 140–155. https://doi.org/10.1007/s11244-023-01817-4

Vargas Soplín, A. de J., Meyer-Aurich, A., Prochnow, A., & Kreidenweis, U. (2024). Alternative uses for urban autumn tree leaves: a case study in profitability and greenhouse gas emissions for the city of Berlin. *Journal of Cleaner Production*, *470*, Article 143290. https://doi.org/10.1016/j.jclepro.2024.143290

Vishwakarma, M. C., Joshi, H. K., Joshi, S. K., & Bhandari, N. S. (2022). Biosorption Study of Pb(II) Ions onto Treated *Eupatorium adinoforum (AEA)* and *Acer Oblongum (AAO):* Thermodynamic and Equilibrium Studies. *Applied Science and Engineering Journal for Advanced Research*, *1*(3), 1–13. https://doi.org/10.54741/asejar.1.3.1

Wu, K., Cui, K., Huang, Y., Yu, K., Chen, X., Li, C. X., & Chen, Y. (2024). Degree of human activity exert differentiated influence on conventional and emerging pollutants in drinking water source. *Environmental Science and Pollution Research*, *31*(5), 7214–7226. https://doi.org/10.1007/s11356-023-31440-5

Yaparov, I. M. (Ed.). (2005). *Atlas respubliki Baškortostan* [Atlas of the Bashkortostan Republic]. Roskartografiya.

Zamparas, M., Tzivras, D., Dracopoulos, V., & Ioannides, T. (2020). Application of Sorbents for Oil Spill Cleanup Focusing on Natural-Based Modified Materials: A Review. *Molecules*, *25*(19), Article 4522. https://doi.org/10.3390/molecules25194522