Application of the rain gardens for surface runoff treatment in moderate climate

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Abstract. A technical solution for the use of rain gardens for treatment of surface runoff in a moderate climate is proposed. The experience of implementing a pilot rain garden for the treatment of surface runoff from the parking of the tenement building is described. Study results of the efficiency of surface runoff purification from suspended substances, petroleum products and some heavy metals in a pilot rain garden are presented. Recommendations for improving the quality of treated surface runoff are given. The directions of further research of rain gardens are outlined.

1. Introduction
Drainage and treatment of stormwater and meltwater is an important problem of urban areas ecology and creation of a comfortable urban environment. One of the approaches to the control of surface wastewater which is becoming increasingly widespread in the world practice is the use of bioengineered structures, including rain gardens (phytofilter, stormwater bioretention filter). Many industrial countries have developed programs, regulations, and guidelines for the design and operation of such facilities, for example, Low-impact Development (LID) in the United States and Canada, Water Sensitive Urban Design (WSUD) in Australia, Sustainable Urban Drainage System (SUDS) in the United Kingdom, and Sponge City in China [1, 2]. Bioengineered structures in these countries are classified as the best management practices (BMP) for surface runoff management which combine high efficiency, environmental friendliness, moderate cost of construction and operation, as well as aesthetic appearance in the urban environment.

A rain garden is a lowered area of the territory designed to receive stormwater and filled with a filtering media in which water-resistant plants are bedded out. Wastewater treatment takes place during filtration process implemented by the filtrating media and root system of plants. The main limitation of the rain gardens application in a moderate climate, typical for most of the territory of the Russian Federation, is a decrease in the activity of plants and soil microorganisms at low temperature which leads to a reduction in effectiveness of structures in the periods of autumn and spring [3]. An engineering solution alternative to traditional approaches has been proposed. It provides to introduce into filtering media the materials which have sorption and ion exchange properties, for example peat and zeolite [4–7], and make possible to block up and accumulate dissolved impurities (petroleum products, heavy metals) in the periods of low temperatures. Later, the accumulated impurities undergo transformation, stabilization and degradation under the influence of the processes of vital function of plants and soil microorganisms during their activity in summer [8, 9]. This ensures the natural recovery
(phytoregeneration) of the filtering media. It makes possible to ensure the year-round high quality of surface runoff treatment and long-term operation of the media until its sorption properties are exhausted.

Previously a set of studies of the processes of suspended substances, petroleum products and heavy metals extraction on multicomponent media, as well as the processes of phytoregeneration of media with the use of aquatic higher plants was carried out in the laboratory [10]. For the further introduction of this technology in the surface runoff treatment experience it is necessary to study the work of raingardens in areas with a moderate climate in the urban environment.

In 2017 a pilot rain garden was developed and applied for the treatment of surface runoff from the parking of the multi-family residential building, the address of which is 3, Arkady Gaidar Street, Perm, located in close proximity to the small Uinka River.

2. Materials and methods

Calculation of the rain garden was carried out by the author’s developed procedure based on the assumption that the drainage area (asphalt coat) is equal to 0.10 ha, precipitation depth subjected to runoff treatment due to the criteria amounted to 70% of the annual runoff volume from the area – $h = 7 \text{ mm}$.

Calculation of the rain garden area $S_{rg}$ is made taking into account the necessity of runoff waters volume accumulation of the predicted rain from the provided with sewerage system territory on the surface of rain garden the layer of which is at most $h_l$ and its further response during 24 hours.

$$S_{rg} = \frac{W_{tr}}{h_l},$$

where $W_{tr\text{oc}}$ – calculated volume of weather elements (of rainwater or melt-water) subjected to runoff treatment is determined according to the procedure [11], m$^3$;

So, starting with the necessity of operating calculated volume of sewage waters within 24 hours minimum filtration rate amounts to:

$$v_{\text{min}} = \frac{h_l}{24} = \frac{0.3}{24} = 0.0125 \text{ m/h}$$

The following configuration of rain garden filling was adopted (figure 1): 100 mm – coarse sand; 300 mm – multicomponent media consisted of zeolite, peat and sand at the ratio 1:9 by volume, 300 mm – sand. Under the tile line there is the supporting layers of gravel with fraction of 5-20 mm and height of 200 mm each where the drainage and slotted corrugated pipes of 100 mm in geotextile have been placed.

![Figure 1](image-url)
Rain garden is equipped with overflow made of stacks and mounted in 300 mm over the filling surface and connected with the outlet line. At that, the depth of the rain garden “cup” with regard to surrounding surface amounts to 400 mm.

For the acceptance of the stormwater flow from the car parking it was provided the break in the curb stone and asphalt-concrete gutter. To prevent washing out of the filtering media in the place of flow income in the rain garden it was thrown the gravel. Outlet line was mounted outside the territory with the outfall from the valley of Uinka River.

Peat of the Paltinsk deposit (Krasnokamsk city) was used as the material having the sorption and ion-exchange properties. Properties of peat in relation to petroleum products and heavy metals had been determined earlier and given in table 1, 2 [12].

| Names of indicators | Reference documentation of test methods | Codes of National State Standard | Signification |
|---------------------|----------------------------------------|---------------------------------|---------------|
| Botanical composition | National State Standard 28245-89 | - | mixed, mainly pinaceous-sphagnous and cottongrass-sphagnous |
| Organic substance, % | National State Standard 26213-85 | - | 86.7 |
| Ash-content, %, at most | National State Standard 11306-83 | 25 | 13.3 |
| The rate of the peat decomposition, %, not less | National State Standard 10650-72 | 25 | 26.6 |
| Acidity pH of salt suspended solid (pH KCl), not less | National State Standard 11623-89 | 4.60 | 4.60 |

| Pollution            | Langmuir equation constants | Freundlich equation constants |
|----------------------|-----------------------------|--------------------------------|
|                      | $A_\infty$ | $K_L$ | $\beta$ | $n$ |
| Petroleum products   | 500.00 | 0.01 | 0.86 | 1.02 |
| Pb                   | 46.08  | 0.18 | 4.99 | 2.32 |
| Cu                   | 38.76  | 0.13 | 6.48 | 2.18 |
| Zn                   | 26.60  | 0.17 | 4.84 | 2.19 |
| Fe                   | 44.05  | 0.13 | 6.41 | 1.93 |
| Al                   | 22.08  | 0.12 | 2.90 | 1.93 |

The basic substance of the tile line was the constructional sand, National State Standard 8736-93. Earthwork operations were completed in August, 2017 (figure 2a, b). In October the following kinds of higher plants were bedded out: Iris pseudacorus, Phalaris arundinacea, Mentha aquatica (figure 2b).
During the summer of 2018 it was observed the flashy growth of the bedded plants and up to July-August firm ground vegetation cover was formed (figure 2d).

To define the efficiency of the construction operating performance it was made water sampling and analysis before and after treatment. Sampling of the original flow was made from the water in the supplying asphalt-concrete gutter. Sampling of the filtered water was supposed to be made from the draft tubes mounted in the slope of Uinka river valley. However, in the process of low intensity raining it happened water infiltration into the underlying local soil (probably the imported sand soil used in formation of the adjacent territory), and the level of water in the hand-pitched stone subbase was under the marks of the infiltration tunnel. At that, under the exit of the draft tube it was formed a streamlet which became the source of water extraction.

Petroleum products control before and after sorption was implemented by gravimetric method according to PND F 14.1:2.116-97. The content of heavy metals was determined by photometric procedure with Spectroquant NOVA 60. Suspended solids content in the standardized test solution of the surface waste waters before and after treatment was defined by the gravimetric method according to PND F 14.1.2.110-97.

3. Results and discussion
The results of analysis of the original and treated surface runoff testing are given in table 3.
The efficiency of treatment in the considered rain garden amounted to: from suspended solids - 82.5-98.8%, from petroleum products - 77.6-92.5%, from total ion – 55.6-95.0%, from chromium – 25-83.3%, from zink – 55.6-88.4%.

When further quality growth of the runoff filtering from dissolved impurities is required (for example, for fishery waters disposal), in the multicomponent treatment of rain it is required further examination of the rain garden one could recommend the application of cartridge-type filters for sorptive additional treatment of wells, and application of more sorptive materials including minerals.

Analysis of the effective treatment from organic impurities, examination of changing the delivery value of filtering media, including at low temperatures, and analysis of heavy metals content in the phytomass of plants bedded out in the rain gardens could be specified as the direction of further research.

4. Conclusion
The use of rain gardens for treatment of surface wastewaters including in the moderate climate territories is the innovative solution. The first experience of the rain garden application has shown high efficiency of filtering surface runoff from suspended solids, petroleum products and heavy metals. For the widespread use of surface runoff treatment it is required further examination of the rain gardens operation on the territories with moderate climate in conditions of urban environment.

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