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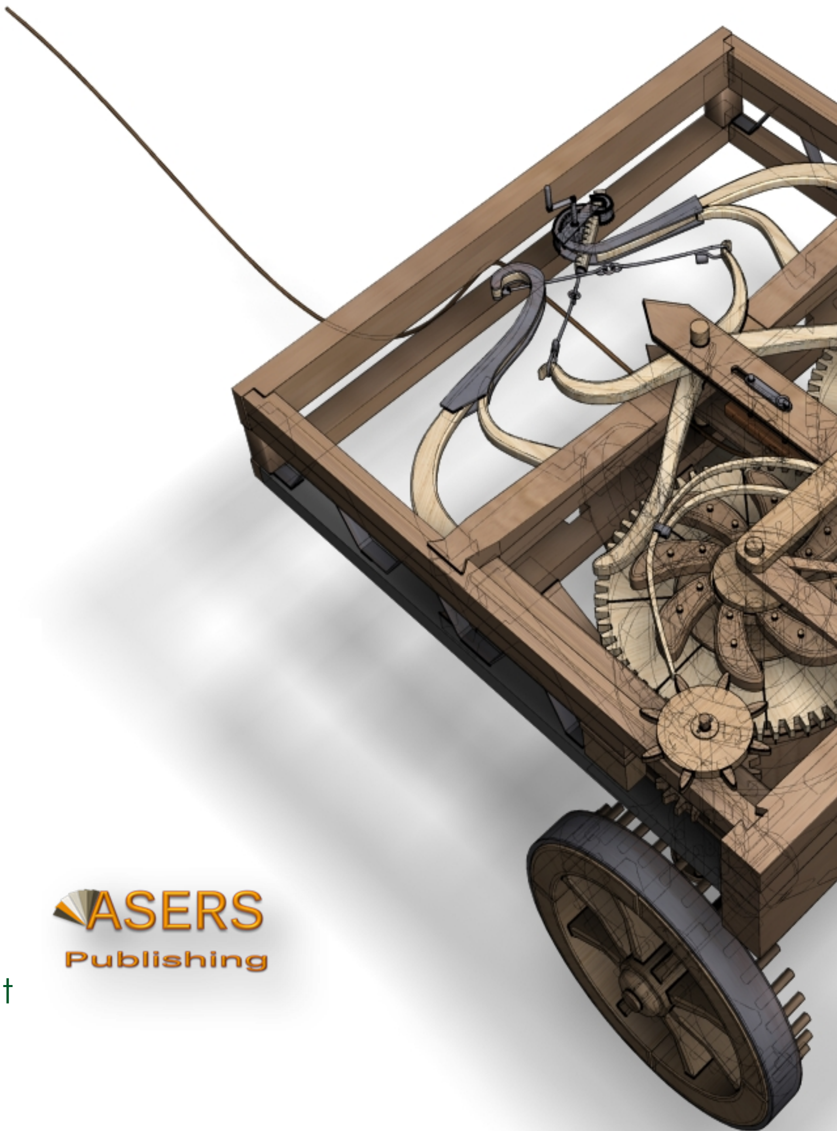

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Scientific Rationale for the Use of Wastewater as an Alternative Source of Irrigation under Water Deficit

Sergey Mikhaylovich VASILYEV
Russian Research Institute of Land Improvement Problems, Russian Federation
scholar3365@gmail.com

Yulia Evgenyevna DOMASHENKO
Russian Research Institute of Land Improvement Problems, Russian Federation
domachenko_u@list.ru

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Abstract:

This article presents the scientific rationale for the application of wastewater as an alternative source of irrigation under water deficit. The purpose is to develop technological solutions for the use of the drainage effluent as an alternative source of water in reclamation systems. This research investigated the process of filtration through the filter element, which is made on the basis of coal production waste and has a cylindrical shape with a cavity inside that is filled with the sorbent based on rice husks, and developed a method for the preparation of the drainage effluent for the agricultural use. Studies of the filtration process were carried out on the models of the radial pressure filter.

The results of the conducted research on the pressure loss increase in the filter element have shown that when the diameter of the grains of the filter element is increased, there is a reduction in the pressure loss increase with respect to time. At d_g=0.18 mm the critical dirt-holding capacity starts at 3 hours of the filtration process, at d_g= 0.23 mm – 6 hours, and at d_g=0.71 mm –14 hours. The efficiency of purification when using the developed filter element depending on the diameter of the grains and the filtration rate decreases over time, and towards the end of the filtration cycle (15 hours), their content is reduced from 8.2 to 0.2 mg/dm^3 at a uniform filtration rate. The method helps to improve the quality of the preparation of the drainage effluent for crop irrigation, to expand the range of the use of drainage water, having a different chemical composition, and to simplify the process of installation of the filter elements through the use of more light weight construction.

Keywords: water resources; drainage effluent; method of preparation; irrigation; filter element.

JEL Classification: Q57.

Introduction

Russia ranks second in the world in gross fresh water resources (after Brazil), and third among the largest countries in the water availability per capita (after Canada and Brazil). The specifics of water use in Russia is low efficiency; particularly dangerous are the accidental discharges of contaminated water associated with accidents at wastewater treatment plants, and the illegal discharges of wastewater bypassing treatment plants at night. This leads to the rapid pollution of surface and, in some cases, subsurface sources of the water supply, as a result of which about 35% of the water samples from these sources do not meet the quality standards. In Russia, the annual cost of water pollution in the first years of the XXI century averaged about 70 billion rubles (at 2001 prices), and in recent years, this figure has increased (Danilov-Danilyan 2009, Rodda 1997).

The world's bulk of the water consumed, 70% - is used in agriculture, mostly for irrigation. For example, to grow 1 ton of wheat sold in the world market, on average, it is required to use 1 thousand m^3 of water. A significant portion of water, 20% is used in the manufacturing industry, and the rest of it, 10% goes to municipal services.

Water deficit will increase, if the process of environmental degradation is not stopped. This implies that the necessary condition for solving the problem of water deficit is the reduction of the anthropogenic impact on the environment, the environmentalistonof production and consumption, the development of resource-saving technologies for the disposal of wastewater in the agricultural sector.

The current trend of systematic income and accumulation of pollutants in surface and subsurface water, the use of the contaminated drainage effluent for irrigation brings to the forefront the development of technical and technological solutions helping to reduce the risk of the release of heavy metals, pesticides and other toxic elements and compounds in the agricultural field. The water migration of pollutants within the reclaimed area is characterized by the development of processes of the translocation and accumulation of toxicants and their compounds in the soil, subsurface water and agricultural products (Kontorovich 2007, Domashenkoand Vasilyev 2016, Ovchinnikova 2013, Kapustyan, Yuchenko and Starostina 2003, Bezdnina 1997a, 1997b, Bezdnina and Ovchinnkova 2000, Bezdnina 2013, Domashenko and Vasilyev 2015, Shchedrin and Vasilyev 2011).

The purpose of this paper is to develop technological solutions for the use of the drainage effluent as an alternative source of water in reclamation systems. Scientific novelty of the research consists in the application of the filter element in the drainage effluent treatment which is made on the basis of coal production waste and has a cylindrical shape with a cavity inside that is filled with the sorbent based on rice husks.

The main objectives of conducted studies were as follows:

- to study the filtration process through the filtering element made on the basis of coal production waste having a cylindrical shape with a cavity inside, filled with the sorbent based on rice husks;
- To develop a method for the preparation of the drainage effluent for the agricultural use.

1. Literature review

In the territory of North Carolina (USA), the system of drainage water use, based on the regulation of its volumes through the installation of controlled drainage in the drainage network, has received considerable attention in recent years. Controlled drainage may be installed on subsurface drains as well as in open ditches, making it possible to adjust the water table at any depth from the ground surface to the drainage (Strock *et al.* 2010).

Studies have shown that such controlled drainage helps to reduce the nitrate-nitrogen concentration, on average, by 40% to 50%, and respectively, that of phosphorus by 25% to 35%. The widespread use of controlled drainage is limited to the need for the modernization of existing drainage networks to accommodate the flow control system, which requires both capital and then current significant investment. An important factor is also the connection of this system to the terrain and the configuration of the irrigated site.

Studies on a willow plantation as a photo-ameliorant when irrigated with contaminated agricultural drainage water, carried out in 1993-1995 in the south-west of Sweden, have showed a certain practicality. The soil for planting was sand with an admixture of clay. The planting of trees was dense, 2×104 plants per hectare. In the spring of 1994, furrows were made between each second plant row at a depth of 20 cm. Water was fed into these furrows and distributed within the territory during the growing season. The drainage water used for irrigation was supplied by the closed pipeline, which provided the fertilizing watering of 700 hectares of agricultural land. The content of nitrate nitrogen of the irrigation water was about 10-17 mg/la the chosen site was irrigated from May to November with an intensity of 11 mm/day. The meanevapotranspiration from the site was 5 mm/day, on average.

The excessive amount of moisture was distributed in the soil profile, whereby nitrogen was assimilated by the root system. The amount of nitrogen delivered during 1995 to the plantation with the drainage effluent was within 185 kg*N* per hectare. The nitrogen content in the green mass varied from 25 to 47 mg N/g during the growing period. The high nitrogen content in the leaves and the biomass during the growing season showed that the willows received enough nitrogen compounds. This demonstrates the possibility to use them as a vegetation filter as far as the willow root system effectively absorbs and converts nitrogen from the drainage effluent (Elowson 1999).

There were also field trials in the arid region of Pakistan on the cultivation of wheat and cotton irrigated with the saline drainage effluent. Before irrigation the salinity of drainage effluents was reduced by the dilution with canal fresh water. The study included: dilution of the drainage effluent with natural water (electrical conductivity (EC) 1.25 Ds $м^{-1}$) without irrigation of crops; irrigation with the drainage effluent (EC 2.25 Ds $м^{-1}$) alone; irrigation with the drainage effluent and green manure; irrigation with the drainage effluent and liquid manure. In the research of crop yields, a number of indices were taken into account: changes in the infiltration rate, soil salinity and solidity. The maximum yield of 88.9% was set when the drainage effluent was diluted with green manure and liquid manure. In case of the dilution of the drainage effluent with liquid manure, soil salinity and solidity decreased by 2.8 and 41.3%, and leaching increased by 39.2 and 14.9% at a depth of 0-15 cm. At other depths, soil sampling revealed that all types of irrigation with the drainage effluent significantly increased soil fertility. At the same time, the concentration of sodium increased at a depth of 60-90 cm, regardless of the type of treatment. The use of liquid manure in the dilution of the drainage effluent helped to obtain the highest yield of wheat and cotton with an average of 1925 and 1485 kg ha, respectively. Overall, the results showed that the use of liquid manure for the dilution of the drainage effluent was more effective than other forms of treatment in the aspect of reducing the negative effects of the use of saline drainage effluents. However, the use of liquid manure with the drainage effluent is recommended under the acute shortage of water for irrigation (Kahlown and Azam 2003).

In arid and semi-arid regions of India, wastewater from the closed drainage is often saline and in the absence of an effective method of treatment, its disposal is a serious environmental threat. A field experiment was conducted for 7 years with the use of drainage water of different salinity levels (ECiw = 6, 9, 12 and 18.8 Ds/m) for irrigation of wheat in the dry winter season. The purpose was to prove whether it is possible to produce crops when irrigated with drainage water and how this will affect the intensity of soil salinity. The experimental crop was obtained for wheat grown during the winter season, and pearl millet and sorghum in the rainy season. Crops were grown on a sandy soil and were irrigated with drainage water from the closed drainage system. Before sowing, crops were pre-irrigated with canal fresh water, and then with drainage water of varying salinity levels. On an average, the reduction in wheat yield at different ECiw was 4.2% at 6, 9.7% at 9, 16.3% at 12 and 22.2% at 18.8 Ds/m. The yield of pearl millet and sorghum significantly decreased at 12 Ds/m and above. The high salinity and solidity of drainage water increased soil salinity in the soil profile under irrigation during the winter season. However, this problem was fixed in a natural way during the subsequent monsoon periods. The research has shown that the findings provide a promising option for the use of poor quality drainage water for the irrigation of winter wheat without excessive reduction of soil yield and degradation (Sharma and Rao1998).

The research of an IFDM system (integrated on-farm drainage management) conducted in the US has shown that this system helps to apply drainage water as irrigation water for the guaranteed yield and to reduce the amount of drainage water discharged into water bodies (Tanji and Kielen 2002, Wichelns 2005, Cervinka 2001). According to the adopted technology, drainage water is used consistently for the irrigation of crops, trees and shrubs with a gradually increasing salt tolerance. Drainage water is gradually redistributed within the distinguished areas, while the volume of wastewater is reduced and its salinity increases. The classical IFDM system consists of four areas:

- Area 1, where salt-sensitive crops such as vegetables, fruits, beans and corn are grown;
- Area 2, where salt-tolerant crops such as cotton, sorghum, and wheat are grown;
- Area 3, where trees and shrubs are grown;
- Area 4, where only halophytes are grown.

At the last stage, the drainage effluents discharged into a solar evaporation system.As shown by the analysis of the existing methods of application of the drainage effluent for the irrigation of crops, the priority area is the dilution of the drainage effluent with clear water or its use without prior preparation, but in this case, it is necessary to maintain the crop rotation with the predominance of salt-tolerant crops. It was also determined that in the world practice there are no engineering-environmental or engineering-reclamation systems, which make it possible to use the potential of drainage effluents to the full extent without causing secondary pollution of the environment: subsurface water, soil covering, surface watercourses. The current trend in this area necessitates the search for resource-saving and environmentally friendly methods of the preparation of drainage water for the irrigation of crops.

2. Materials and methods

The research of the process of filtration through the filtering element, which is made on the basis of coal production waste and has a cylindrical shape with a cavity inside that is filled with the sorbent based on rice husks, was carried out on the models of the radial pressure filter. The model of the radial filter is a cylindrical sector with a central angle of 60^0 and a height of 30^0 mm. The input filtration square was 0.0273 m^2. The design and dimensions by the radius of the model filter chamber fully comply with the dimensions of the production filter sample that is why the filtration process based on them is close to the regularities of filtration based on the production filter (Figure 1).

The construction of themodels as follows: abode 1 is made of sheet steel. The body has a louvered wall 10 at the center, so that between the body wall and the louver there is a chamber for the source water 2, in which the water is conducted through a pipe 3.

From the top, the body is hermetically closed with a cover 4. In the cover, from the chamber of the source water, there is a hole for a manometer 9, moreover, on the inside of the cover there are ribs 12 made with an interval of 8 cm along the full width of the chamber. When the cover is closed, the ribs are in contact with the filter material 5 and thereby prevent wall filtration.

Around the peripheral wall of the body, at a certain distance from it, there is a perforated baffle 11. The space between the wall and the baffle is a holding chamber for a filtrate. The filtrate is removed through a pipe 7, and the pressure in the chamber is measured by a manometer 9.

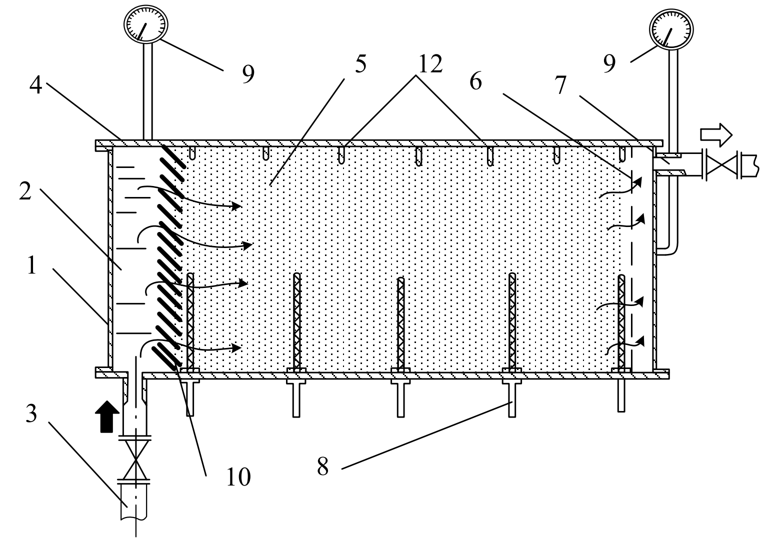
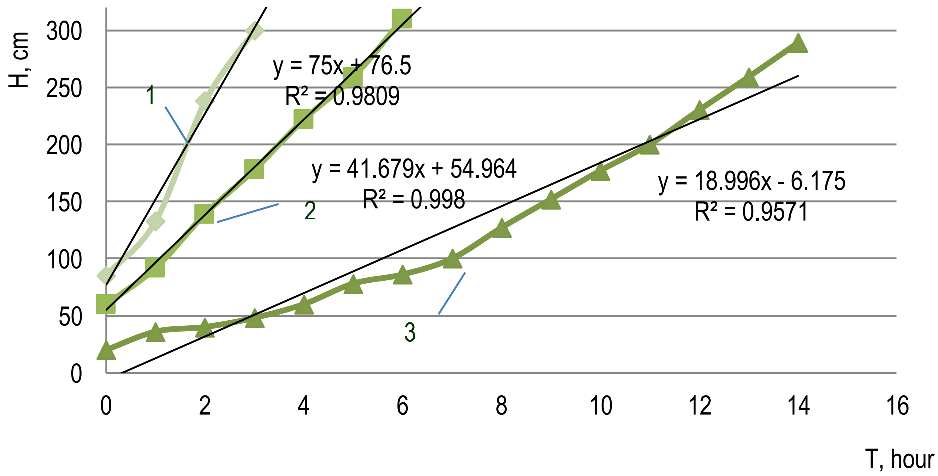


Figure 1 -Structure of the radial filter model

3. Results

Studies conducted by various authors have shown that the size of the pore chambers in polymer-concrete loading is dependent on the diameter of the grains forming the given filter element (Ayukayev and Meltzer 1985, Frog and Levchenko 1996, Yakovlev and Voronov 2004, Korenevsky, Korenevsky and Konovalov 2000). Therefore, at the first stage of the research, it is necessary to study the optimum diameter of the loading grains at which the filtration process will proceed as smoothly as possible. The results of the research on the pressure loss increase in the filter element at a different grain diameter are shown in Figure 2.



Note: 1 – $d_з$=0, 18 мм; 2 – $d_з$=0, 23 мм; 3 – $d_з$=0, 71 мм

Figure 2 - Pressure loss increase in the filter element at a different grain diameter.

As shown by this dependence, when the diameter of the grains of the filter element is increased, there is a reduction in the pressure loss increase with respect to time. At d_g = 0.18 mm the critical dirt-holding capacity of the filter element starts at 3 hours of the filtration process, at d_g = 0.23 mm – 6 hours, and at d_g = 0.71 mm – 14 hours.

The efficiency of purification when using the developed filter element depending on the diameter of grains and the filtration rate has also been studied. The findings are summarized in Table 1.

Table 1 - Results of the research on the efficiency of purification of the drainage effluent in filter loading with a grain diameter of 0.71 mm

No. experiment	Sampling time, h	Suspended materials concentration in the source water, mg/dm^3	Suspended materials concentration in the filtrate, mg/dm^3	Filtration rate, m/h	Pressure loss, m	Water temperature, ^{0}C
1	10.00	264	8,2	20,2	39	18,2
2	10.20	230	2,6	19,8	45	18,2
3	10.40	200	1,5	19,7	51	18,2
4	11.00	240	0,9	19,4	58	18,2
5	12.00	230	0,6	19,3	78	18,2
6	13.00	245	0,5	18,6	101	18,3
7	14.00	232	0,6	18,5	119	18,3
8	15.00	260	0,4	19,2	140	18,3
9	16.00	236	0,3	19,6	156	18,3
10	17.00	240	0,3	19,5	174	18,3
11	8.00	232	1,5	19,4	196	18,0
12	9.00	245	0,3	19,5	218	18,0
13	10.00	230	0,3	19,4	236	18,0
14	11.00	242	0,2	19,1	256	18,0
15	12.00	210	0,2	18,0	278	18,0
16	13.00	220	0,2	18,1	294	18,2

Based on the results, it was found that over time the efficiency of purification is reduced. This is confirmed by the concentration of suspended materials in the filtrate – by the end of the filtration cycle, their content is reduced from 8.2 to 0.2 mg/dm^3 at a uniform filtration rate.

Discussion

Based on the studies conducted, a method for the preparation of the drainage effluent has been developed with the purpose of its secondary use for the irrigation of crops that reasonably helps to reduce the man-caused impact of this category of water on the environment.

In the proposed method, at the first stage of purification a separator is used, and, respectively, at the second stage - a filter pit, which includes the filter elements based on coal production waste, produced by the known formula (RU D No. 249844 IPC B01D 39/06, B01D 20/02, C02F 1/00 of November 20, 2013, Bull. No. 32), having the shape of a cylinder with a cavity inside. The isolated cavity is filled with a sorbent based on the rice husk, which in turn is put into bags made of the basalt fabric VATI TBK-100 for easy replacement or regeneration of the spent sorbent (Shchedrin *et al.* 2015).

The method is implemented in the following scheme: a separator that will help to remove coarse mechanical impurities from the water with 70-80% purification effect, and a filter pit, which is filled with the filter elements based on coal production waste, produced by the known formula, having the form of a cylinder with a cavity inside. The isolated cavity is filled with a sorbent – a sorbent based on the rice husk, which in turn is put into bags made of the basalt fabric VATI TBK-100 for easy replacement or regeneration of the spent sorbent. Studies have shown that the effect of purification by heavy metals and salts may reach 85-90%.

According to the proposed method, the drainage effluent with an initial content of suspended materials of 10 mg/dm^3 is first supplied to a separator, where 80% of suspended materials (2 mg/dm^3) are removed and there is a preliminary loss of heavy metals and salts by 20% of the initial content. Then, the water is supplied to the filter pits, where drainage water has an advanced treatment by suspended materials of up to 99%, by salts of heavy metals - to 95% and by hardness salts - to 91%.

The results of the research of the chemical composition before and after the preparation of the drainage effluent for the irrigation of crops are presented in Table 2.

Table 2 - Results of studies before and after the preparation of the drainage effluent for the irrigation of crops

No.	Cl^-, g/dm^3	SO_4^{2-}, g/dm^3	HCO_3^-, g/dm^3	Ca^{2+}, g/dm^3	Mg^{2+}, g/dm^3	Na^{2+}, g/dm^3	pH	Amount of ions, g	Dry residual, g	Cu, mg/dm^3	Fe, mg/dm^3
1	0,956	1,296	0,334	0,140	0,240	0,639	8,01	3,675	3,700	0,50	2,65
2	0,156	1,025	0,124	0,031	0,120	0,296	7,60	3,012	3,100	0,06	1,21

The method helps to improve the quality of the drainage effluent preparation for crop irrigation, to expand the range of the use of drainage water, which has a different chemical composition, to simplify the process of installation of the filter elements through the application of the lighter filter element and to reduce the deficit of irrigation water in the areas of wastewater formation and uncontrolled discharge.

Conclusions

The current trend of systematic income and accumulation of pollutants in surface and subsurface water, the use of the contaminated drainage effluent for irrigation brings to the forefront the development of technical and technological solutions helping to reduce the risk of the release of heavy metals, pesticides and other toxic elements and compounds in the agricultural field.

As shown by the analysis of the existing methods of application of the drainage effluent for the irrigation of crops, the priority area is the dilution of the drainage effluent with clear water or its use without prior preparation, but in this case, it is necessary to maintain the crop rotation with the predominance of salt-tolerant crops. It was also determined that in the world practice there are no engineering-environmental or engineering-reclamation systems, which make it possible to use the potential of drainage effluents to the full extent without causing secondary pollution of the environment: subsurface water, soil covering, surface watercourses. The current trend in this area necessitates the search for resource-saving and environmentally friendly methods of the preparation of drainage water for the irrigation of crops.

The results of the research on the pressure loss increase in the filter element have shown that when the diameter of the grains of the filter element is increased, there is a reduction in the pressure loss increase with respect to time. At d_g=0.18 mm the critical dirt-holding capacity of the filter element starts at 3 hours of the filtration process, at d_g=0.23 mm – 6 hours, and at d_g=0.71 mm – 14 hours. The efficiency of purification when using the developed filter element depending on the diameter of grains and the filtration rate is reduced over time. For example, by the end of the filtration cycle (15 hours), the concentration of suspended materials in the filtrate is reduced from 8.2 to 0.2 mg/dm^3 at a uniform filtration rate.

The proposed method helps to improve the quality of the drainage effluent preparation for crop irrigation, to expand the range of the use of drainage water, which has a different chemical composition, and to simplify the process of installation of the filter elements through the application of more lightweight construction. Moreover, this method makes it possible to reduce the deficit of irrigation water in the areas of wastewater formation and uncontrolled discharge.

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