Water Science & Technology

IWA PUBLISHING

Water Science & Technology Vol 00 No 0, 1 doi: 10.2166/wst.2021.512

An investigation into the role of treatment performance and soil characteristics of soil-based wastewater treatment systems

N. Baykuş [a,*] and M. Karpuzcu [b]

[a] Department of Construction, Vocational School of Technical Sciences, Kilis 7 Aralık University, Kilis, Turkey
[b] Department of Civil Engineering, Faculty of Engineering, Hasan Kalyoncu University, Gaziantep, Turkey
*Corresponding author. E-mail: nurdanbaykus@kilis.edu.tr

NB, 0000-0002-6199-3363; MK, 0000-0001-7488-0977

ABSTRACT

Soil-based onsite wastewater treatment systems (OWTS) are becoming more important for the treatment and disposal of wastewater in areas that have not central wastewater collection and treatment systems. However, there are concerns that OWTS may have adverse effects on public health and environment. The purpose of this study is to treat wastewater with using natural soil column in order to evaluate treatment system performance. Wastewater was applied to two different natural soils at different flow rates of 9, 18 and 36 L/day. The treatment performances of wastewater and geotechnical properties of the natural soils were examined. As a result of this study, the percentage of COD and SS removal in wastewater after soil column filtration were range from 36.2% to 80.5% and 84.4% to 97.9% respectively. pH values of wastewater after the filtration were measured between 7.75 and 8.12. TP and TN removal rates were found in the range of 23.9–76.8% and 12.4–83.0%, respectively. The column effluent water were classified as both 'high hardness class' in terms of hardness and 'polluted water' in terms of conductivity. Column effluent water were found in 'low, medium, and high hazard' classes in terms of SAR. Whereas the PL values of the natural soils were found to increase by up to 4.8% in filtration area, specific gravity decrease nearly 1.1%. The values of LL, PI, maximum dry density, optimum water content, and permeability were changed depending on the soil type. The UCS of the natural soils after wastewater filtration decreased by about 5.9%. It was concluded that natural soils have positive effects on treatment of wastewater in short time.

Key words: domestic wastewater, flow rate, soil-based wastewater treatment, soil characteristic, soil filtration

HIGHLIGHTS

- Wastewater treatment was achieved at different flow rates using natural soil columns.
- The average removal rates for COD, SS, TP, and TN by the natural soil columns reached up to 80.5%, 97.9%, 76.8%, and 83.0%, respectively.
- The influent water properties had a high impact on wastewater treatment.
- Geotechnical properties of natural soils were slightly affected by short-term filtration.

1. INTRODUCTION

Wastewater treatment systems by soil-based have been greatly used in the world. For example, approximately 13% (more than 2 million people) of the Australian population does not have a sewage system (Thomas *et al.* 1997; Dawes & Goonetilleke 2003). According to 2016 TURKSTAT data, approximately 15.8% of Turkey's population does not have sewerage networks. About 38.5% of the population in Poland (14.7 million people) live in rural areas and over 35% of them have not sewage systems, including wastewater treatment plants (Boguniewicz-Zabłocka & Capodaglio 2017). It has been reported that approximately 21% of American homes have OWST and 95% of these are septic tank field systems (Sato *et al.* 2019).

Septic tanks are an important system for domestic wastewater treatment. It can be accepted as an ideal system for villages, separate houses, hotels, resorts, and sites in both rural and urban areas without centralized wastewater collection systems. This system is generally consist of one or two septic tanks and a soil drain field. Sedimentation of solid particles in the wastewater and anaerobic decomposition of organic materials occur in the septic tank. After the wastewater is retained in a septic

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tank until sedimentation completion, it is transported to the soil drain field. Then, wastewater is purified by filtering in the soil (Lopez Zavala *et al.* 2002; Sato *et al.* 2019).

In previous studies has stated that septic tanks system can lead to adverse effects on public health and environment and also pollutants can be carried into groundwater (Scandura & Sobsey 1997; DeBorde *et al.* 1998; Paul *et al.* 2000; Richards *et al.* 2016). One of the reason in adverse effect of septic tanks system is that all site and soil types do not have adequate treatment and distribution capacity of wastewater (Siegrist *et al.* 2000; Whitehead & Geary 2000; Carroll *et al.* 2006). The researchers, such as Levine *et al.* (1980); Schipper *et al.* (1996); Van Cuyk *et al.* (2001) have identified the nature of the site and soil conditions as the main limitation in the performance-based design of septic systems. Filter failure may occur when such soil areas are subjected to conditions of heavy loading as a result of degradation of the soil's physical condition caused by pore-clogging (De Vries 1972). From this perspective, the comprehensive understanding of the factors that mainly affect treatment performance in the design of wastewater disposal areas and the need for adopting performance-based management strategies is gaining increasing recognition (Dawes & Goonetilleke 2003; Sheeja *et al.* 2019).

The soil is an excellent environment that allows the retention of contaminants in wastewater (Dawes & Goonetilleke 2003). Based on previous studies, contaminants in wastewater by the soil can be provided retention of the biological oxygen demand (BOD) and chemical oxygen demand (COD) (Li *et al.* 2015), nitrogen (Küçükçongar & Sevil 2020), phosphate (Gholizadeh *et al.* 2016), microbial pathogens (Gilbert *et al.* 1976) and organic materials (Sato *et al.* 2011). Then, these contaminants are possible to be decomposed by microbial activities and absorbed by relatively exchangeable ions (Sato *et al.* 2019). More applied studies have included regionally sourced soil filtration practically for treatment the domestic wastewater (Li *et al.* 2015), cassava wastewater (Oluremi *et al.* 2012), textile wastewater (Oriola & Saminu 2012), leachate from unsanitary landfills (Yidong *et al.* 2012), heavy industrial wastewater (Ortega *et al.* 2008) and olive mill wastewater (Ait-hmane *et al.* 2018), etc.

As it is known that wastewater contains many organic and inorganic substances and many microscopic contaminants (Feigin *et al.* 1991). As a result of the interaction of the soil with these contaminants, its physical, chemical, biological, and mechanical properties can be changed. This case may affect the performance of the originally designed filtration field. As the urban sprawl continues and the population increases in rural areas, different purposes of use of these filtration areas may emerge.

This study provides information about the effects of soil-based wastewater treatment systems on both the wastewater treatment performance and geotechnical properties of natural soils. filtration fields to simulate a natural soil column to treat wastewater were developed. Laboratory and field-scale studies were conducted to determine before and after the leakage properties of natural soils and wastewater.

2. MATERIALS AND METHODS

The approach adopted in this study involves the treatment of raw sewage water obtained from a central wastewater treatment plant influent water by filtration in two different natural soil columns and at different flow rates. As a result of this filtration, wastewater treatment performances of natural soils and the effects of structural differences between columns on wastewater treatment efficiency were revealed. At the same time, it was determined the effects of the filtration in the short term on the properties of soils.

2.1. Experimental description and processing

The experimental study area of this study is a central wastewater treatment plant located in Oğuzeli/Gaziantep/Turkey. The plant is located at 36.940708 latitude and 37.441172 longitude and has an area of approximately 3,000 m^2. A pilot plant in this study was arranged at the raw influent water section of the central wastewater treatment plant (Figure 1).

As it can be seen in Figure 1, the pilot plant consists of two sedimentation tanks, one submersible pump, and natural soil columns. A submersible pump was placed in the influent water of the wastewater treatment plant at its location in Figure 2 and the raw influent wastewater was pumped into the 1st sedimentation tank with a capacity of 1,000 L. Then, the wastewater was retained in the tank for 24 hours to presedimentation of solids. After the presedimentation was completed, the water was transferred from the flood level of the 1st tank to the 2nd sedimentation tank with a capacity of 1,000 L. The wastewater in 2nd sedimentation tank was retained for 24 hours to provide complete sedimentation. Then, wastewater was fed from the upper part of plexiglass natural soil columns at different flow rates respectively 9, 18, and 36 L/day. Flow rates were determined in relation to soil volume. The effective working time of the soil columns was 23 days. Since the water pumped

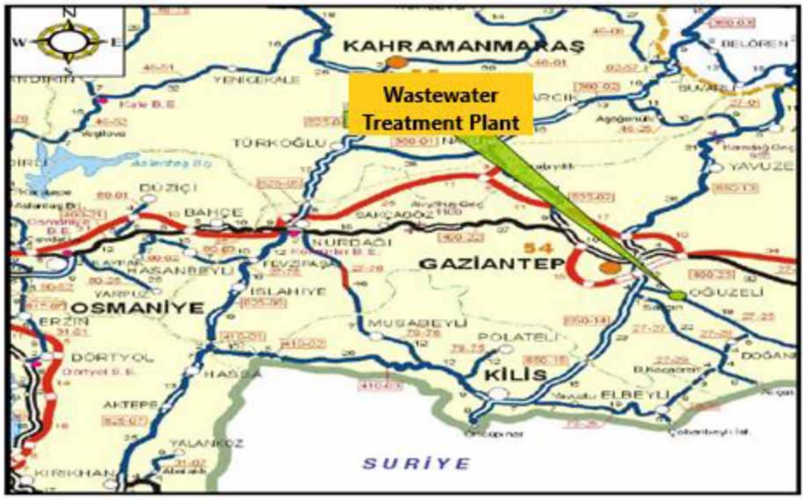

Figure 1 | Schematic demonstration of pilot plant.

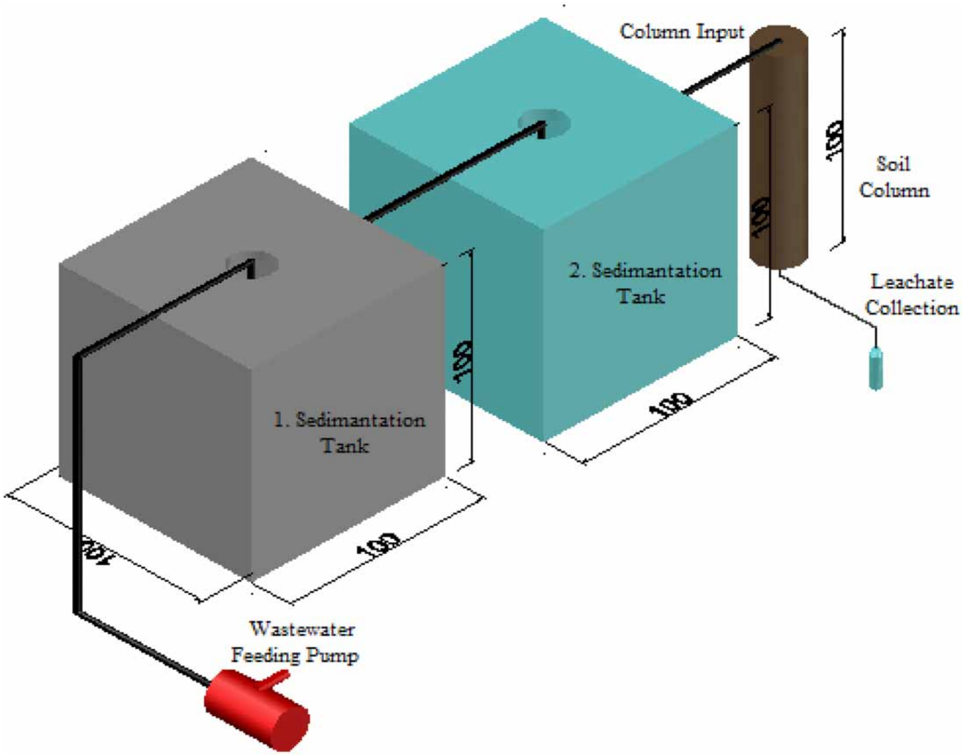

Figure 2 | Location notification map, Gaziantep/Turkey.

from the raw influent water to the sedimentation tanks was subjected to a retention period of 2 days. The soil columns were operated during 21 days uninterruptedly.

Natural soil column details used in this study are given Table 1. The upper and lower parts of the natural soil columns were filled with 20 cm gravel each to provide drainage. 8 mm or 5 mm diameter sieve filters were placed at the lowest part of the natural soil columns. Wastewater passing through the filters was collected from the drainage effluent at the bottom of the natural soil column at an average of 48-hour intervals.

Table 1 | Natural soil column details

Soil-column experiment	NSA			NSŞ		
Plexi Glass Column (cm)	100			100		
Soil Thickness (cm)	60			60		
Soil Weight (g)	30,150.43			33,520.19		
Drainage (cm)	20 + 20			20 + 20		
Type of Soil	Natural			Natural		
Saturation Conditions	Unsaturated			Unsaturated		
Water Type	Domestic Wastewater			Domestic Wastewater		
Injection Method	Continuous			Continuous		
Injection Flow Rate (L/day)	36	18	9	36	18	9
Experiment Time (days)	23			23		
Experiment Season (month)	August–September			July–August		

2.2. Water sampling and quality measurement

In order to evaluate the wastewater treatment efficiency, a total of 10 column influent and effluent water samples were taken every 48 hours from each natural column with different flow rates. Chemical oxygen demand (COD), suspended solids (SS), conductivity, and pH value, total nitrogen (TN), total phosphate (TP) sodium (Na), calcium (Ca), magnesium (Mg), and potassium (K) analyzes were performed. Sodium adsorption ratio (SAR) (Richards 1954) was calculated using the following equation;

$$SAR = \frac{Na^{+}}{\sqrt{\frac{[Ca+2]+[Mg+2]}{2}}}\,(\mathrm{ppm}) \tag{1}$$

In the scope of the study, COD was measured by the closed reflux colorimetric method (Standard Method 5220 D). Conductivity was measured by Hanna Instrument HI-2315 and Ph was measured by Hanna Instruments HI-2211. SS analysis was performed by Standard Methods 2540D. Elemental analyzes were determined by ICP-Optical Emission Spectroscopy (Optima 8000 ICP-OES). TN and TP were determined with commercial kits. TN measurement method is photometric. TP test kits are in the standard of ISO 6878_2004, DIN EN 6878/D11.

2.3. Soil sampling and characteristic measurements

Natural soils were collected from two different rural areas. Natural soil samples from these areas were excavated from a depth of 150–200 cm. While some of the samples collected in airtight bags with a capacity of 100 kg were brought to the laboratory, the other part was transported to the study area for the preparation of columns. Natural soils were stored in airtight bags at room temperature until their actual use. The natural soils used are referred to as NSA and NSŞ in this study.

Firstly, the natural soil columns were prepared at the bulk density of the soils to represent the field conditions of filtration. Bulk density was determined according to the procedure in ASTM D7263-09. After that, sieve and hydrometer analysis were performed by ASTM D422-63 and ASTM D7928-17 in order to classify the natural soil with using ASTM D2488-00. The following experiments were performed before and after wastewater filtration and the properties of natural soils were compared.

Specific gravity (ASTM D854-14), Atterberg limit (ASTM D4318-00), compaction (ASTM D1557), permeability (ASTM D5084-00), unconfined compressive test (UCS) (ASTM D2166), as well as scanning electron microscope (SEM) imaging (Model-ZEISS/EVO LS10) were performed. The properties of the natural soils are given in Table 2.

2.4. Statistical design of experiments

Data were subjected to one-way ANOVA and the post-hoc Tukey test was used to compare their means. The normality test was checked to ensure the distribution of the data. The relationships between influent and effluent were given at the level of significance ($p < 0.05$).

Table 2 | Characteristics of natural soils (NSA and NSŞ)

	NSA	NSŞ
Soil Properties		
Sieve and Hydrometer Analysis		
Gravel (%)	10.27	5.22
Sand (%)	24.24	8.46
Silt (%)	36.10	59.17
Clay (%)	29.39	27.15
Classification	CL	CL
$\omega_{natural}$ (%)	9.2	7.6
Bulk Density (γ_n) (gr/cm^3)	1.70	1.89
Porosity (n) (%)	38.30	30.40
Atterberg (Consistency) Limits		
LL (%)	48.9	45.1
PL (%)	23.4	23.4
PI (%)	25.5	21.7
G_s	2.76	2.72
Standard Compaction Test		
γ_{kmax} (ton/m^3)	1.60	1.61
ω_{opt} (%)	23.489	21.054
Unconfined Compressive Strength (UCS)		
q_u (kPa)	203.60	186.70
ε (%)	1.90	3.18
Permeability (cm/sn)	9.16×10^{-9}	1.17×10^{-8}

3. RESULTS AND DISCUSSION

3.1. The effect of natural soils on wastewater treatment performance

3.1.1. Removal of chemical oxygen demand (COD)

COD is a measure of the oxygen equivalent of organic materials in wastewater and a largely used indicator of wastewater quality (Kang *et al.* 1999). The higher the COD value in the water can lead to increase the water contamination of organic matter (Li & Liu 2019). Many countries have stringent regulations on the discharge of wastewater with a high concentration of COD (Ezechi *et al.* 2015). For example, a maximum COD must be between 200 and 1,000 mg/L before wastewater can be recycled into the environment in Switzerland (Sawyer *et al.* 2003; Li & Liu 2019). While the Department of Environment of Malaysia revised the COD discharge limit for sewage effluents standard 'A' to 120 mg/L (Ezechi *et al.* 2015), the wastewater discharge standard published by the Ministry of Environment and Forestry in Turkey has been limited to 120–180 mg/L (e-Legislation no: 7221).

As it can be seen in Figure 3, all the natural soil column has positive impacts on COD removal from wastewater regardless of the excessive fluctuation of influent wastewater. The influent water COD value of the NSA column was found an average of 417.28 ± 110.34 mg/L. COD concentrations in the effluent water of NSA column were found a reduction in ratio 72%, 80.5, and 36% at flow rates of 9 L/day, 18 L/day, and 36 L/day, respectively. The influent water COD value of the NSŞ column was an average of 323.14 ± 119.02 mg/L. The COD concentrations of the effluent water of NSŞ column were found an average of 70.33 ± 49.41 mg/L, 89.76 ± 58.55 mg/L, and 145.18 ± 76.95 mg/L at flow rates of 9 L/day, 18 L/day, and 36 L/day, respectively. When the influent and effluent water of NSŞ column are compared, COD removel efficiency ranges between 65.0% and 78.5%. It can be said that the average of COD values of effluent water from natural soil columns were found to be compatible with the discharge standards (e-Legislation no: 7221). For the COD parameters, the difference between the influent and effluent water was statistically significant ($p < 0.05$).

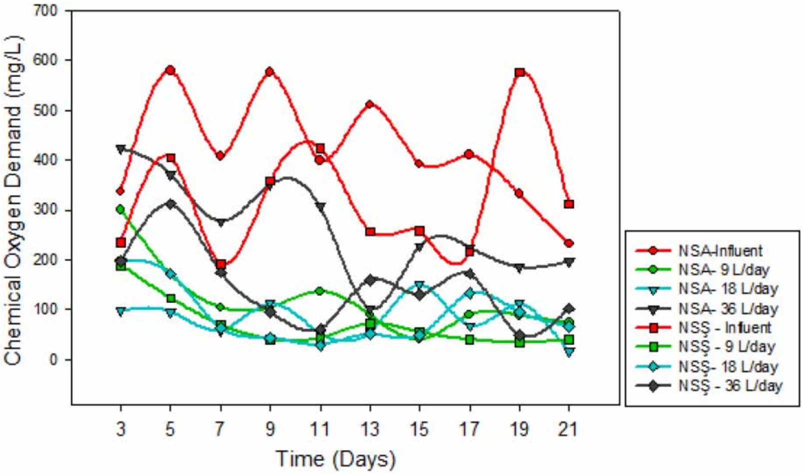

Figure 3 | The COD removal efficiency by filtration of NSA and NSŞ columns.

3.1.2. Removal of suspended solids (SS)

SS plays an important role in characterizing the treatability and the level of contaminant removal in wastewater. Therefore, the removal of SS is one of the essential criteria in wastewater treatment (Ahsan *et al.* 2001). The SS removal efficiency of wastewater with natural soils are presented in Figure 4.

The average influent water SS concentrations were found to be 418 ± 424.6 mg/L and 248.74 ± 257.56 mg/L in the NSA and NSŞ columns, respectively. The removal efficiency of SS as a result of filtration in natural soils varied between 84.4% and 97.9%. The highest SS removal efficiency was achieved in the NSŞ column fed with a flow of 9 L/day. NSŞ is a dominant natural soil in terms of the presence of fine grains. However, there have been studies that have resulted in between 99–100% removal of SS independent of the particle size effect of soil (Ahsan *et al.* 2001). Therefore, this is not an obvious reason. As the flow rate in the columns increased, the average of SS removal efficiency decreased slightly. For the SS values, statistically significant differences were found at the $p < 0.05$ level in the comparison between the columns influent and effluent water. As a results of SS analysis, effluent water is similar for all-natural soils. These results have provided the wastewater standards discharge values (e-Legislation no: 7221). Similar results have been reported elsewhere (Todt *et al.* 2014; Karpuzcu *et al.* 2020). Chun *et al.* (2008) found that the influent water SS concentration was 184 mg/L, while the effluent water SS concentration was 6–17 mg/L.

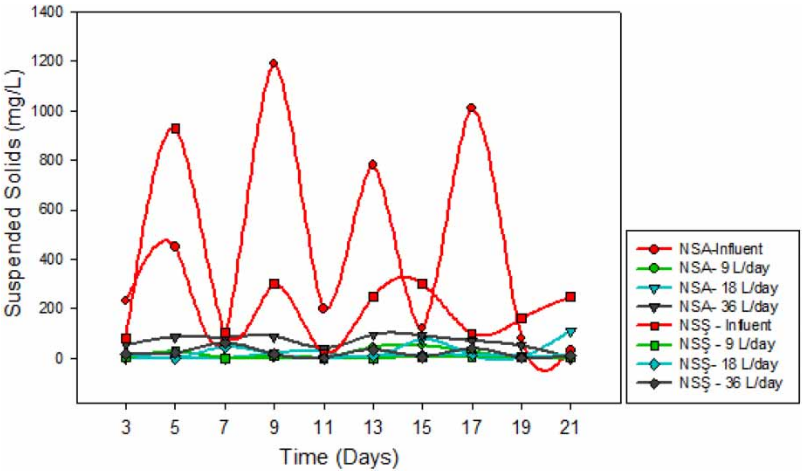

Figure 4 | The SS removal efficiency by filtration of NSA and NSŞ columns.

3.1.3. pH and conductivity of wastewater

pH is a parameter in the water system that affects the living conditions of microorganisms and the functioning of chemical reactions (Li & Liu 2019). It is a measure of whether water is acidic or basic and is a value between 0–14 on a defined scale. According to the regulation, the pH value of the wastewater is required to be between 6–9 before being discharged to the receiving environment (e-Legislation no: 7221). If the pH value of the water is too high or too low, microorganisms living in the water and solubility or chemical reactions may be affected (Li & Liu 2019).

Conductivity is a parameter to determine water quality. It is a measure of the ability of water to conduct electricity (Crescentini *et al.* 2012). This ability is directly related to the concentration of ions in the water (Li & Liu 2019). The higher the dissolved ion concentration lead to the higher the conductivity of the water (Çaldırak & Kurtuluş 2018). A sudden increase or decrease in conductivity in a body of water may indicate pollution in the water (Li & Liu 2019).

The pH and conductivity results of the study are given in Table 3. Accordimg to pH results of all samples, it can be stated that the average pH value of each influent and effluent water is below the discharge limits (e-Legislation no: 7221). pH results are similar to the research conducted by Suarez & Gonzalez-Rubio (2017). They have determined that the raw wastewater could be equivalent to or less than the treated wastewater. While there were a statistically significant differences for the pH values of influent and effluent water of NSŞ ($p < 0.05$), no statistically significant differences were found for the NSA column ($p > 0.05$).

The conductivity results were evaluated according to Table 4 classification, the effluent of all soil columns is classified as 'III-Polluted water'. The seasonal changes of conductivity values were investigated by Okur *et al.* (2001); Igbinosa & Okoh (2009); Ucun Özel & Gemici (2016). They stated that the conductivity value of wastewater could be higher in summer and lower in winter. Higher conductivity values measured in natural soil columns in the summer months are compatible with previous studies. When the conductivity of the column influent and effluent water are evaluated, there were no statistically significant differences for the NSŞ column fed with a flow rate of 9 L/day and for the NSA columns ($p > 0.05$), while there were a statistically significant differences in the NSŞ columns fed with a flow rate of 18 and 36 L/day flow rates ($p < 0.05$).

3.1.4. Total phosphorus (TP) and total nitrogen (TN) removal efficiency from wastewater

Phosphorus is found in wastewater in three main forms which orthophosphate ion, polyphosphate or condensed phosphate and organic phosphorus compounds (Özacar & Şengil 2003; Gholizadeh *et al.* 2016). TP is the combination of these forms of phosphorus, which is usually measured in milligrams per liter of water (Li & Liu 2019). Domestic wastewater may contain from 5 to 20 mg/L of TP, of which 1–5 mg/L is organic and the rest is inorganic (Larramendy & Soloneski 2016).

Table 3 | pH and conductivity results of natural soil column influent and effluent water

Soil type	Influent		9 L/day Effluent		18 L/day Effluent		36 L/day Effluent	
	pH	Conductivity	pH	Conductivity	pH	Conductivity	pH	Conductivity
NSA	7.59 ± 0.42	2,166.10 ± 427.8	7.75 ± 0.23	2,051.50 ± 172.4	7.86 ± 0.18	1,948.20 ± 246.1	7.86 ± 0.28	2,297.00 ± 212.3
NSŞ	7.68 ± 0.29	1,488.70 ± 337.7	8.10 ± 0.21	1,119.40 ± 376.5	8.12 ± 0.24	1,106.70 ± 517.0	8.07 ± 0.21	1,160.00 ± 255.9

The results are given with the arithmetic mean and standard deviation. The unit of conductivity is μS/cm.

Table 4 | Quality criteria by class of intra-continental surface water resources (e-legislation no: 28483)

Conductivity (μS/cm)	Water quality classes
<400	I: High-quality water
400–1,000	II: Lightly polluted water
1,001–3,000	III: Polluted water
>3,000	IV: Very polluted water

TN is the sum of organic nitrogen and inorganic nitrogen in the water, especially reflecting the degree of water pollution (Gross & Boyd 1998). There are forms of nitrogen that are commonly measured in water bodies: organic nitrogen, ammonia, nitrates, and nitrites. According to the literature, the total nitrogen concentration of typical raw domestic wastewater varies between 20–85 mg/L, dissolved organic nitrogen concentration of 8–35 mg/L, ammonia nitrogen concentration in the range of 12–50 mg/L, while nitrite and nitrate-nitrogen concentrations are quite low (Küçükçongar & Sevil 2020).

In this study, the average TP measurements of the influent water in the NSA and NSŞ columns were found to be 4.45 ± 2.01 mg/L and 4.19 ± 0.70 mg/L, respectively. The average TN measurements for the NSA and NSŞ columns were found at 53.10 ± 8.49 mg/L and 52.40 ± 9.88 mg/L, respectively. The highest average TP removal was reached 76.8% at the NSA column fed with a flow rate of 9 L/day. TP removal efficiency decreased as the flow rate increased in NSA and NSŞ columns (Figure 5). A similar relationship was also seen in TN removal efficiency (Figure 6). The lowest TN removal efficiency was 12.4% in the NSA column fed with 36 L/day flow rate. The TP removal efficiency of natural columns varied between 23.9%–76.8%, while the TN removal efficiency ranged between 12.4% and 83.0%. For TN measurements, it was found to be statistically significant in the comparison between the column influent and effluent water ($p < 0.05$). In terms of TP, while there was no statistically significant difference in NSA and NSŞ columns fed with 18 L/day and 36 L/day flow rates, respectively ($p > 0.05$), the difference between other operated soil columns was statistically significant ($p < 0.05$).

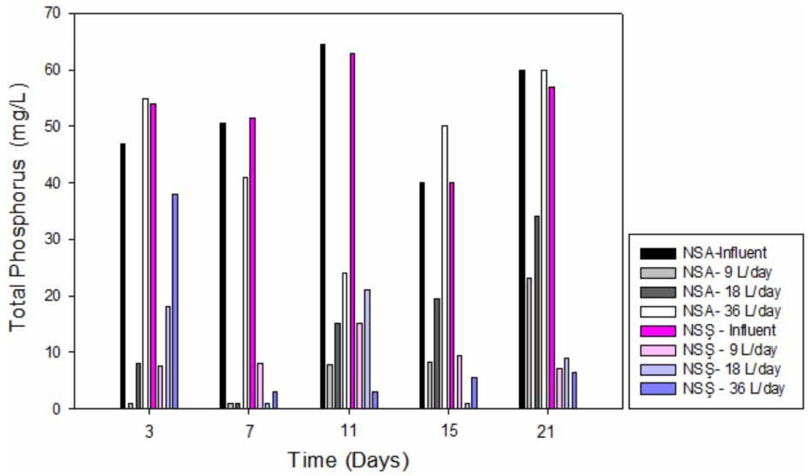

Figure 5 | TP removal efficiency of NSA and NSŞ columns.

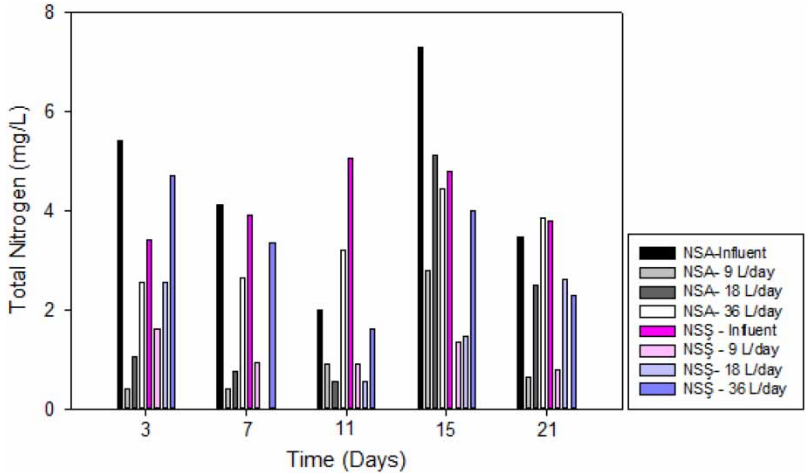

Figure 6 | TN removal efficiency of NSA and NSŞ columns.

3.1.5. Evaluation of sodium adsorption ratio (SAR)

SAR is a water quality parameter that indicates whether the water is suitable for irrigation or not. It expresses the relative activity of ion exchange of cations in irrigation water and soil structure. It is also used to predict the infiltration rate problem in the soil (Richards 1954).

The sodium hazard classes based on SAR are presented in Table 5 (Richards 1954). The classification of columns influent and effluent water based on SAR are given in Table 6. The effluent water collected from NSŞ classified as a 'S1-Low or no hazard'. The average effluent water of NSA columns fed with a 9 L/day and 36 L/day flow rate is classified as a 'S3-High hazard'. The interaction of the NSA column and water associated with the highly exchangeable sodium content may have formed an unstable structure (Wang *et al.* 2016). Special soil management, good permeability, good drainage, and organic matter addition, etc. may be required for such filtration fields. In a study by Metzger *et al.* (1983), it was observed that 8%–26% of soluble Ca and Mg in wastewater could bind to organic molecules and as a result, the effective SAR value of the wastewater can be increased.

If the irrigation water contains high Na, the Na in the water can displace Ca and Mg in the soil. This can reduce the permeability of the soil and thus causing infiltration problems (Bourrie 2014; Sivakumar *et al.* 2015). The results of elemental analyzes of influent and effluent water to natural soil columns are given in Table 7. If the Ca and Mg concentrations in the effluent decrease or the Na concentrations increase, it can lead to an increase in the SAR value of the soil (Jnad 2000).

3.1.6. Total hardness

Hardness can be defined as a measure of Ca and Mg dissolved in water (Dudziak & Kudlek 2019). Generally, water containing calcium carbonate below 75 mg/L is considered soft. Medium hard, hard, and very hard water are classified as 75–150,

Table 5 | Rating of water samples concerning salinity and sodium hazard (Richards 1954)

Sodium hazard class	SAR (mg/L)	Remark on quality
S1	0–10	Low or no hazard (low Na water)
S2	10–18	Medium hazard – Appreciable (medium Na water)
S3	18–26	High hazard – Doubtful (high Na water) (Problems on most soils)
S4	>26	Very high hazard – Unsuitable (very high Na water)

Table 6 | Classification of the influent and effluent water of soil columns in terms of SAR

Soil type	Sample	SAR (mg/L)	Remark on quality
NSA column	Influent	11.37 ± 7.85	*Medium hazard – Appreciable*
	9 L/day effluent	21.70 ± 9.53	*High hazard – Doubtful*
	18 L/day effluent	10.86 ± 13.50	*Medium hazard – Appreciable*
	36 L/day effluent	21.17 ± 10.41	*High hazard – Doubtful*
NSŞ column	Influent	10.37 ± 10.94	*Medium hazard – Appreciable*
	9 L/day effluent	3.10 ± 1.83	*Low or no hazard*
	18 L/day effluent	3.22 ± 1.93	*Low or no hazard*
	36 L/day effluent	6.06 ± 3.98	*Low or no hazard*

Table 7 | Elemental analyses of influent and effluent water

Soil Type	Influent				9 L/day Effluent				18 L/day Effluent				36 L/day Effluent			
	Ca	Mg	Na	K	Ca	Mg	Na	K	Ca	Mg	Na	K	Ca	Mg	Na	K
NSA	90.82	23.25	82.9	63.72	173.76	29.36	221.98	20.15	164.46	25.84	88.72	37.31	98.28	28.95	172.94	98.29
NSŞ	135.6	30.59	88.91	60.09	*145.37*	*27.95*	*30.21*	*1.89*	118.72	24.39	29.66	2.16	112.44	24.94	48.46	6.82

The results are given with the arithmetic mean. The unit of element analysis is mg/L.

150–300, 300 mg/L, and above, respectively (Samsunlu 2011). In this study, the total hardness was calculated with the following equation depending on the Ca and Mg concentration (Hammes *et al.* 2003).

$$\text{Total Hardness} = [2{,}497 \times Ca^{+2}] + [4{,}118 \times Mg^{+2}](\text{mg/L}) \tag{2}$$

The average influent water hardness of NSA and NSŞ columns were found at 307.67 ± 139.16 and 464.60 ± 227.86 mg/L, respectively. The average effluent water hardness degree as a result of soil filtration was found the maximum 554.78 ± 115.88 mg/L and the minimum 364.61 ± 100.68 mg/L (Figure 7). Influent and effluent water hardness averages of the natural soil columns can be classified as ‘very hard’. When the difference between columns influent and effluent water was evaluated in terms of hardness, no statistically significant difference was found ($p > 0.05$).

Substances that can be easily dissolved or degraded in the soil structure can affect the hardness of the wastewater (Tölgyessy 1993). In a study by Khanbilvardi & Long (1985), it was observed that the limestone-based soil medium caused an increase in the hardness of the wastewater. An increase in water hardness can be expected due to an increase in the Ca value in the effluent water (Zhang & Shan 1999).

3.2. The effect of wastewater filtration on selected natural soil properties

The physical, chemical, biological, and mechanical properties of the soil can be affected by the contaminants in the wastewater. Moreover, the soils can be very sensitive to the dissolved ions in the wastewater. These dissolved ions can change reflex properties of the soil, including soil composition, particle distribution, soil stability, porosity, and water retention (Kahapanagiotis *et al.* 1991).

In recent years, the widespread use of OWTS for wastewater treatment and disposal has required a good understanding of the effects of wastewater on soil properties. In this respect, there is a need many studies for investigating the effect of wastewater on soil properties. Comparing Table 2 and Table 8 reveals how natural soils are affected by wastewater filtration in the short term.

3.2.1. Atterberg (consistency) limits

Atterberg limits are one of the most common tests used in geotechnics. It is associated with many physical and mechanical properties of soils (Sivapullaiah & Sridharan 1985). Therefore, Atterberg limits can be used as a precursor to predicting many important properties of soils. After the wastewater filtration, the LL and PI values of the NSA soil decreased by about 4% and 11.5%, respectively, while the LL, PL, and PI values of the NSŞ soil showed a slight increase. There have been studies in the literature showing an increase or decrease in the atterberg limits in the interaction of soil with wastewater or organic liquids (Mishra *et al.* 2009; Ramya *et al.* 2018). They generally stated that as the salt concentration of clayey soils increased, the LL and PI values decreased. In another study shown that soils contaminated with wastewater increased LL (Karkush & Resol

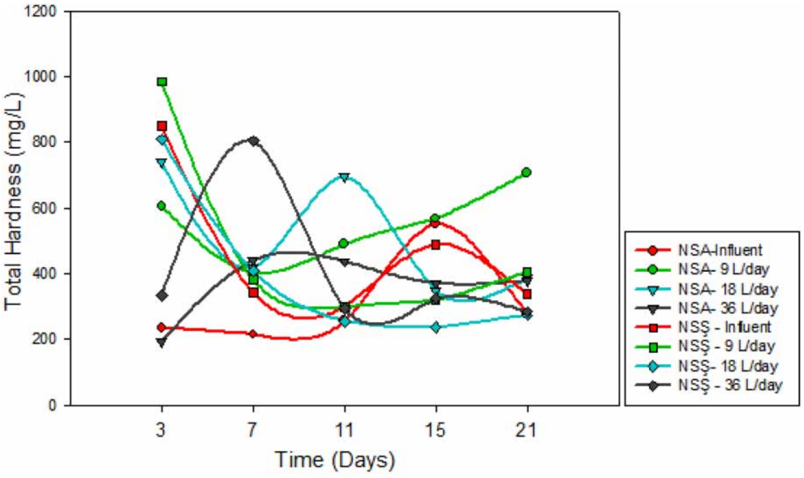

Figure 7 | Total hardness results of NSA and NSŞ columns.

Table 8 | Properties of natural soils as a result of wastewater filtration

	NSA	NSŞ
Soil Properties		
Atterberg (Consistency) Limits		
LL (%)	47.1	48.9
PL (%)	24.5	23.8
PI (%)	22.6	25.1
G_s	2.74	2.69
Standard Compaction Test		
γ_{kmax} (ton/m^3)	1.61	1.60
ω_{opt} (%)	21.302	21.500
Unconfined Compressive Strength (UCS)		
q_u (kPa)	192.6	175.70
ε (%)	2.09	2.77
Permeability (cm/sn)	4.65×10^{-9}	1.36×10^{-8}

2015), PL (Irfan *et al.* 2018), and PI (Jedari & Hamidi 2015) values compared to uncontaminated soils. It can be specified that a liquid with a denser viscosity compared to water may cause more water absorption in soils (Jedari & Hamidi 2015).

3.2.2. Specific gravity (G_s)

Specific gravity is a dimensionless parameter and can be defined as the ratio of the solid density of the soil to the density of water at 20 °C. It is used in geotechnical and geoenvironmental engineering in the calculation of basic physical properties including void ratio, porosity, water content, degree of saturation, and unit volume weight of soil (Yesiller *et al.* 2014). After filtration, there is a slight decrease in the specific gravity of NSA and NSŞ soils. A similar observation has been reported elsewhere (Khan *et al.* 2017; Irfan *et al.* 2018).

3.2.3. Standard compaction test

Compaction characteristics of soil, i.e., optimum water content and maximum dry density are an important engineering characteristics. The compaction properties of soils correlate well with their index properties (Sridharan & Nagaraj 2005). Compaction test results after filtration are shown in Figure 8. There were no significant changes in the maximum dry density of NSA and NSŞ soils after filtration. As for the optimum water content, there was a 9.3% decrease in NSA soil, while an increase of 2.1% in NSŞ soil. There are studies in the literature showing that wastewater pollution increases the optimum water content of soils and decreases the maximum dry density (Oluremi *et al.* 2012; Khan *et al.* 2017; Irfan *et al.* 2018). They stated that soil with a high concentration of contaminants would be difficult to compact and a lower density could

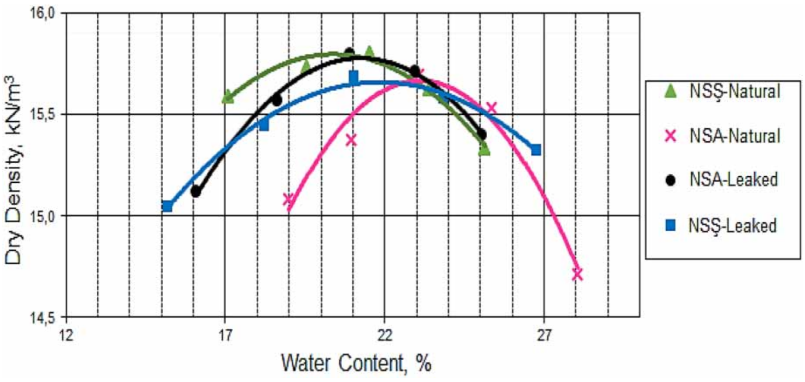

Figure 8 | Compaction curves of soils before and after wastewater filtration.

be obtained compared to uncontaminated soil under the same compaction effort and environmental conditions. On the contrary, studies shows that the optimum water content decreases and the maximum dry density increases (Jedari & Hamidi 2015; Karpuzcu *et al.* 2020).

3.2.4. Unconfined compressive strength (UCS)

UCS refers to the maximum axial compressive stress that the soil can bear under limiting stress. UCS test results for natural soils are given in Figure 9. It was observed that the UCS of natural soils decreased after the wastewater leakage. The strengths of NSA and NSŞ natural soils with the effect of wastewater decreased by approximately 5.9%. The decrease in strength due to the wastewater effect can be attributed to the possible weakening or breaking of soil particle bonds (Umesha *et al.* 2012). The separation of compact particles in the soil due to the leakage effect may cause a decrease in the UCS (Irfan *et al.* 2018). In previous studies observed that similar results were achieved. Studies have been conducted showing that tannery (Stalin *et al.* 2010), textile (Oriola & Saminu 2012) and domestic (Karpuzcu *et al.* 2020) wastewater decrease the UCS of soils.

3.2.5. Permeability test

Soil permeability is the ability of the soil to pass water and air. It depends upon the pores in the soil and how they are connected. Several factors affect the permeability of soils, such as particle size, impurities in the water, void ratio, the degree of saturation, and adsorbed water, to entrapped air and organic material. It is one of the important parameters in terms of design, operation, and efficiency of the filtration fields.

Permeability test results of natural soils before and after filtration are given in Table 2 and Table 8. While the permeability of NSŞ soil were increased slightly after wastewater filtration, the permeability of NSA soil were decreased. Many studies investigated that the effects of organic and inorganic substances, namely the change in soil water chemistry on the permeability of clayey soil (Fernandez & Quigley 1985; Madsen & Mitchell 1989; Ijimdiya 2011; Ramya *et al.* 2018). It is observed that the structure of clayey soils interacting with leachate may deteriorate over time and cause negative interactions that cause shrinkage or cracking (Madsen & Mitchell 1989). In this case, it can be stated that together with a large increase in the permeability of the soils may lead to a decrease in the treatment capacity of the wastewater (Erarslan 2003).

3.2.6. Scanning electron microscope (SEM)

A scanning electron microscope (SEM) can be defined as a microscope that obtains images by scanning the sample surface. In this study, SEM imaging was used to obtain information about the surface morphology and crystal structure of natural soil particles before and after wastewater filtration. Figures 10 and 11 are given the imaging of natural soils at 10 μm diameter and 3.00KX magnification. When SEM images are examined, it can be stated that the soil particles are in a more compact form before filtration. In addition, soil particles are in different tones. Some particles appear blackish, while some particles stand out in dark and light gray or whitish bright colors. Previous studies revealed with SEM observations that it could cause flocculation or dispersion in the microscopic structure of clayey soils after filtration (Chen & Banin 1975; Stawinski *et al.* 1990).

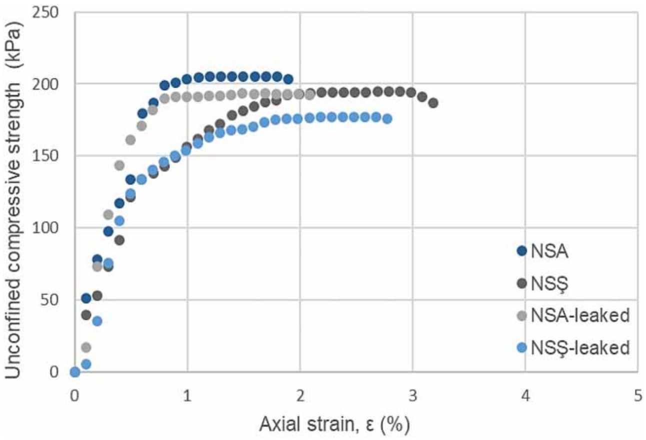

Figure 9 | Stress-strain curves of soils before and after wastewater filtration.

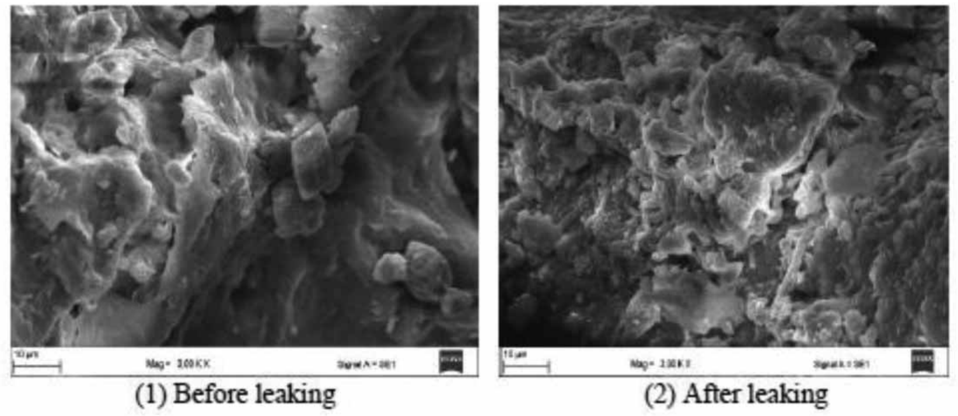
(1) Before leaking
(2) After leaking

Figure 10 | SEM image of NSA natural soil.

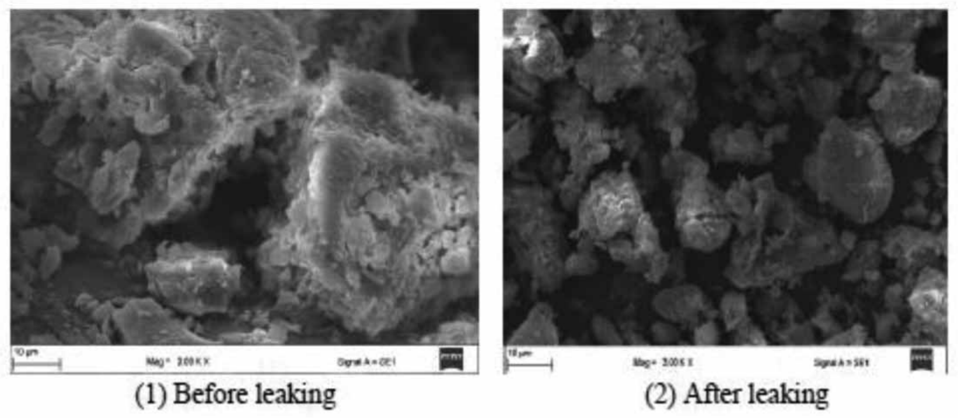
(1) Before leaking
(2) After leaking

Figure 11 | SEM image of NSŞ natural soil.

4. CONCLUSIONS

Soil-based OWST generally consists of the discharge of wastewater into a soil area as the last step, regardless of the first or second sedimentation steps. In this regard, the wastewater treatment ability of the soil needs to be evaluated. Typically, some physical properties of the soil (the permeability rate or the presence of restrictive layers) are important in determining the role of soils in wastewater treatment, protecting the public and environmental health, and supporting system life.

In this study, wastewater treatment was performed using two natural soil columns. The changing properties of soils affected by both wastewater treatment and filtration in the short term were examined. In conclusion; despite excessive fluctuation of influent wastewater to soil columns, 36.2–80.5% COD removal, 84.4–97.9% SS removal, and 7.75–8.12 pH values were found in the effluent water. It could meet the wastewater discharge standard published by the Ministry of Environment and Forestry in Turkey. TP and TN removal rates of natural soils from wastewater varied 23.9–76.8% and 12.4–83%, respectively. As a result of soil filtration, the effluent water was classified as ‘polluted water’ in terms of conductivity and ‘high hardness’ in terms of hardness. NSŞ column effluent water showed a ‘low or harmless level’ of sodium and it was not hazardous for sodium and usable. However, the NSA column was classified as ‘medium and high hazard levels’. Generally, it was observed that the COD, SS TP, and TN removal efficiency were decreased as the flow rate increased. As for the natural soil properties in the filtration area; PL of the soils observed a maximum increase of 4.8%. LL, PI values and permeability were varied according to soil type. The specific gravity of soils were decreased slightly after filtration. There were a decrease in the UCS of natural soils approximately 5.9%.

Soil filtration and wastewater treatment are directly or indirectly related to many complex dynamics such as absorption, chemical reactions, environmental and soil conditions, permeability, etc. It can be said that the pollution load of domestic wastewater is not at an insurmountable level. It can be predicted that the removal of pollutants in the soil columns will increase somewhat if the retention time of the wastewater in the tank is increased to a reasonable level. Thus, the effect of the applied wastewater on the soil structure can be expected to be low due to the lower amount of SS in the wastewater. The further studies are recommended testing component-based treatment and uniform distribution steps over a large soil surface, and especially observing longer-term interactions of soil permeability for the design of filtration fields.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 6 September 2021; accepted in revised form 14 November 2021. Available online 29 November 2021