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AN EXPERIMENTAL STUDY ON TREATMENT OF DOMESTIC WASTEWATER BY NATURAL SOIL

ABSTRACT

In recent centuries, issues such as efficient use of water resources, water quality and water supply have become important for many countries. Countries have focused on developing strategies that can protect water and using water in the most efficient way including treatment of wastewater. In addition, it has become important to provide sustainability of the natural treatment systems instead of complex and expensive wastewater treatment facilities that are rapidly developing. On the other hand, the researches on natural treatment of wastewater are still inadequate. Therefore, the feasibility and performance of new stragtegies about natural treatment systems should be developed and evaluated. For this purpose, a pilot facility was developed which utilizes a natural soil-column with different gradations in order to provide the treatment of domestic wastewater. In this way, not only the wastewater treatment performances of different soils but also some engineering properties of soils affected by wastewater filtration were examined. As a result of this research, it was found that soil filtration can be effective in the treatment of wastewater subjected to pre-sedimentation and can be affected by the pollutant load of the filtration environment.

Keywords: Soil Filtration, Wastewater Treatment, Water Quality, Domestic Wastewater, Soil Structure

1. INTRODUCTION

Water is one of the most important elements on earth, and it is crucial to every living thing in the world. The surface of world is covered with water about 75% but only 2.5% of water is fresh [1]. Industrialization, rapid urbanization, population growth, climate change and environmental pollution are significantly changing the current fresh water quality and the demand for water is steadily increasing [2]. Therefore, it is focused on reducing requirements for fresh water resources worldwide, protecting water resources and developing savings and measures to prevent water pollution. Currently, wastewater treatment and reuse of treated water are suitable option among the savings and measures developed. However, technological wastewater treatment facilities can be difficult to establish and to operate due to the global economy and energy crisis in many developed and developing countries. For this reason, countries have started to implement low cost and low energy natural systems for domestic and industrial wastewater treatment [3 and 27].

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Natural treatment systems can be applied in different methods to solve wastewater problems in residential areas without a central sewerage system. They are often preferred in hotels, restaurants, camps, small facilities, farms, from individual households to settlements up to 2000 inhabitants. In fact, natural wastewater treatment systems are the oldest treatment method known conceptually. Recently, it does not only follow the historical tradition, but also develops with natural treatment technologies, allowing water to be treated in a controlled way of high quality. Essentially, natural wastewater treatment generates spontaneous self-treatment processes during soil filtration through microorganisms [4].

Soil is a suitable environment for removing contaminants in wastewater [5]. However, wastewater can affect the soil properties because the wastewaters contains many mixture of organic and inorganic substances and a large number of microscopic organisms [6, 7 and 8]. Soil properties can change directly or indirectly when the soil's equilibrium structure in natüre interacts with organic and inorganic pollutants caused by environmental conditions [9]. When the literature on this subject is examined, it is possible to come across many experimental and critical studies. Nevertheless, it has been stated that there are limited studies about the effects of wastewater on natural soil. In addition, a contamination process close to land/field conditions could not be simulated in laboratory studies [10]. For this reason, both the evaluation of the treatment capacities of domestic wastewater with soil filtration and some geotechnical properties of the natural soils affected by the application were experimentally investigated in this study.

2. RESEARCH SIGNIFICANCE

Natural treatments can be the most ideal systems for villages, individual houses far from each other, hotels, resorts and sites. This study is important for providing and developing effective solutions for the controlled disposal and recovery of wastewater generated as a result of domestic use in such residential areas. Furthermore, some geotechnical properties of natural soils affected by natural treatment systems were investigated in study. Natural soil with two different gradations was used in this study. Geotechnical examinations were carried out for each natural soil specimen before and after the wastewater was leaked and changes in the engineering properties of the soils were examined. For this study, a pilot-scale facility was developed in field conditions.

3. MATERIALS AND METHODS

In this section, the basis and characteristics of wastewater and soil selection, the details of selected experimental setup and the experiment scheme are presented.

3.1. Research Model, Study Area and Experimental Setup

Experimental field of study is located in the district of Oğuzeli/Gaziantep/Turkey. The study area is Kızılhisar wastewater treatment facility and has an area of approximately 3000 m^2. The study area is located at 36.940708 latitude and 37.441172 longitude location.

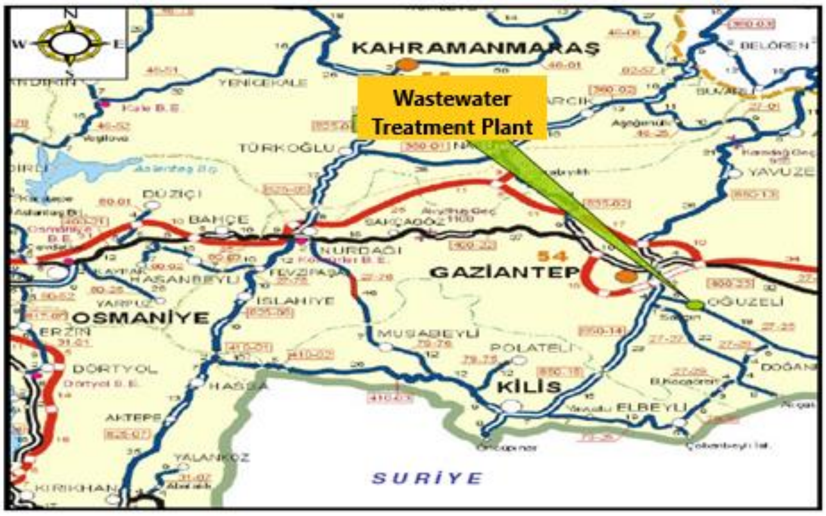

Figure 1. Location notification map

The soil-columns can be stated to be a convenient method that soil-pollutant interaction at various flow rates and retention times, soil leaching potential, transport of pollutant concentration to groundwater etc used to estimate [25 and 26]. For this reason, infiltration and wastewater treatment capacity of soil was investigated in this study with a one-way soil-column.

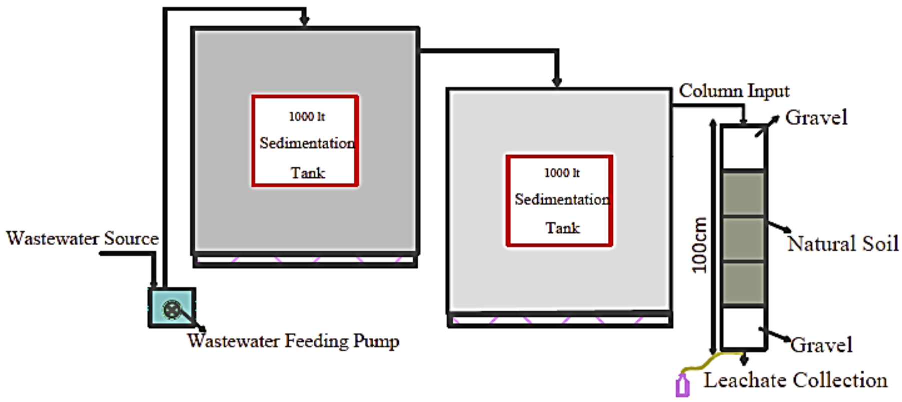

Figure 2. Schematic representation of the pilot facility (unscaled)

A pilot facility was established in the study area at single point (treatment facility inlet water. This pilot facility is composed of a pump thrown into the wastewater treatment facility inlet water pool, 2 sedimentation tanks and soil-columns (Figure 2). In the study, facility inlet water was first pumped into a septic tank with a capacity of 1000 liters and the first sedimentation was performed. After that, when the amount of precipitation in the tank was fixed, the 2nd septic tank was fed from the overflow level of the 1st septic tank. Then, the wastewater at the owerflow level of the 2nd septic tank was fed with a 20cm diameter and 100 cm high plexi-glass transparent soil-column. Finally, analyses were carried out to determine the soil properties and water quality.

3.2. Source and Properties of Wastewater

Wastewater used in the experiment was obtained from the inlet water of Kızılhisar Wastewater Treatment Facility located in Oğuzeli/Gaziantep/Turkey district (Figure 1). The facility was designed for the treatment of domestic wastewater and waste landfill area wastewater.

3.3. Source and Properties of Natural Soils

In this study, natural soil samples obtained from 2 different regions were used. These soil were called G and K. Natural soil samples were taken from a depth of 150-200 cm and transported to the facility. The properties of natural soils are given in Table 1.

Table 1. Characteristics of natural soils (G to K)

Soil Properties	G	K
Sieve Analysis		
Gravel (%)	5.37	19.56
Sand (%)	22.00	2.79
Hydrometer Analysis		
Silt (%)	34.91	35.46
Clay (%)	37.73	23.19
Atterberg Limits		
Liquid Limit-LL (%)	53.4	38.3
Plastic Limit-PL (%)	27.7	21.3
Plasticity Index-PI (%)	25.7	17.0
Classification	CH	CL
Standart Compaction Test		
γ_{kmax} (ton/m^3)	1.53	1.66
ω_{opt} (%)	26.416	18.616
Unconfined Compressive Strength		
q_u (kPa)	227.05	195.45
ε (%)	5.38	3.00
Falling Head Permeability Test (cm/sn)	5.95×10^{-9}	9.64×10^{-9}

3.4. Soil Column Preparation and Operating

Soil-columns designed for the experimental method were prepared in the natural water content and density of soils in order to provide land conditions. In order to evaluate the performance of wastewater filtration at different flow rates, these columns were fed with flow variables associated with total soil volume. The feeding time of soil-columns with wastewater were 23 days. First, the water pumped into the pre-sedimentation tanks in the inlet water of facility were kept in the tanks for 2 days. Later, soil-columns were fed with wastewater.

Water samples were collected at approximately 48-hour intervals (a total of 10 samples) from the drainage outlet located at the bottom of the soil-columns. Chemical oxygen demand (COD), conductivity and pH measurements were performed in these samples. Additionally, hardness and sodium absorption values (SAR) were calculated in the 1st, 3rd, 5th, 7th and 10th samples of the collected samples. Later, the results of soil-column inlet and outlet water analyses were compared. According to these results, the soil's capacity to retention pollutants in wastewater was evaluated.

In order to determine the properties of natural soils affected by wastewater filtration, the properties of the soils given in Table 1 were determined before the soil columns were filled. At the end of 23 days of filtration, artificially contaminated soils with wastewater facility inlet water were carefully collected from the column. Then, the soil tests were repeated. Atterberg limits, compaction, permeability, unconfined compression test (UCS) and scanning electron microscope (SEM) results of contaminated and uncontaminated soil properties were compared.

Table 2. Soil-column operation schema

Soil-column Experiment	G			K		
Type of Soil	Natural			Natural		
Plexi Glass Column (cm)	100			100		
Soil Thickness (cm)	60			60		
Upper and Lower Drainage (cm)	20 + 20			20 +20		
Saturation Conditions	Unsaturated			Unsaturated		
Water Type	Domestic Wastewater			Domestic Wastewater		
Injection Method	Continuous			Continuous		
Injection Flow Rate (lt/day)	36.00	18.00	9.00	36.00	18.00	9.00
Experiment Time (days)	23	23	23	23	23	23

3.5. Analytical Methods

The methods and devices used for wastewater and natural soil analysis conducted within the scope of this study are given in Table 3. These parameters were considered as comprehensive and sufficient to characterize wastewater and to determine its effect on chosen soils.

Table 3. Soil and wastewater tests procedures

Methods	
Analyzes for Wastewater Inlet and Outlet Water	
Sodium Absorption Ratio (SAR)	Elemental analysis result was calculated with the Optima 8000 ICP-OES device.
Hardness	
Chemical Oxygen Demand (COD)	Closed reflux colorimetric method.
pH Value	Hanna Instruments, HI-2211.
Conductivity	Hanna Instruments, HI-2315.
Soil tests before and after wastewater application	
Soil Classification (Sieve Analysis-Hydrometer) *for uncontaminated natural soil.	ASTM D422-02 and D421-85, ASTM D7928-17 and ASTM D422-63(2007)e2 (E100), H152 hydrometer.
Atterberg Limits (LL, PL, PI)	ASTM D4318-00 test methods.
Compaction Test	ASTM D1557 test methods.
Permeability Test	Falling head test methods.
Unconfined Compression Test (UCS)	ASTM D2166 test methods.
Scanning Electron Microscope (SEM)	Model-ZEISS/EVO LS10.

4. RESULTS AND DISCUSSION

4.1. Effect of the Soil Properties on Wastewater

4.1.1. Atterberg Limits

Atterberg limits can be used as a precursor to predict many important properties of soils. The characteristics of limits below wastewater contamination is shown in Table 4.

Table 4. The effects of domestic wastewater on Atterberg limits

Atterberg Limits (%)	G		K	
	Uncontaminated	Contaminated	Uncontaminated	Contaminated
Liquid Limit-LL	53.4	51.2	38.3	42.1
Plastic Limit-PL	27.7	28.0	21.3	22.3
Plasticity Index-PI	25.7	23.1	16.9	19.8

When Table 4 is examined, LL and PI decrease and PL increase are observed in G soil with high plasticity clay (CH) content. LL, PL and PI values have increased in K soil. The increase in soil atterberg limits can be caused by chemical interaction between soil particles and wastewater [11]. The related literature studies show that the atterberg limits of soils increase or decrease due to the effect of pollutants [20 and 22].

4.1.2. Compaction Test

Compaction is an important engineering feature in terms of determining and improving the physical and mechanical properties of soils [31]. The higher the dry unit weight (γ_k) of a soil, the better the soil can be compacted.

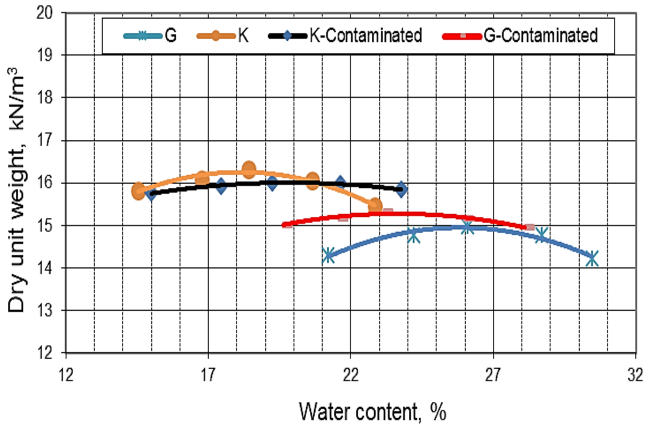

Figure 3. The effects of domestic wastewater on compaction of natural soils

When figure 3 is evaluated, it is determined that the maximum dry unit weight (γ_{kmax}) of G soil increases and the optimum water content (ω_{opt}) decreases due to the effect of wastewater. While γ_{kmax} in K soil decreased, ω_{opt} increased. These results are consistent with previous studies. In a study it has been stated that wastewater increases the maximum dry unit weight of high plasticity clays and reduces the optimum water content [21]. Another study reported that as the pollutant ratio increases, the maximum dry unit weight of contaminated soils may decrease [20 and 32].

4.1.3. Permeability Test

Permeability is the ability of soil to transmit water and air. It is a measure of porosity. As soil porosity decreases, permeability decreases. The permeability test results are given in Table 5.

Table 5. The effects of domestic wastewater on permeability

Falling Head Test (cm/s)	Uncontaminated	Contaminated
G	5.95×10^{-9}	7.00×10^{-9}
K	9.64×10^{-9}	1.06×10^{-8}

It may be possible that permeability may decreases especially when swelling clay minerals are present in soil structure [12]. The higher water retention of soil by the application of wastewater has resulted in a decrease in pore volume and permeability value [16].

4.1.4. Unconfined Compression Test (UCS)

UCS is a measure of strength that can be determined in the case of uniaxial loading without lateral pressure. The strength behavior of soils contaminated with wastewater is shown in figure 4.

The unconfined compressive strength of both soils decreased by approximately 5%. Reduction of strength due to contamination may result from weakening of bonds between soil particles [13]. The possible decomposition of mineral particles in soil is also cited as a cause leading to decrease in soil strength [11]. The decrease in strength and strain depending on the nature of contamination can be attributed to the interaction of pore water viscosity and mineral particles [19]. A study about soils contaminated with wastewater concluded that the unconfined compressive strength of soils can decrease up to 60% over time [11].

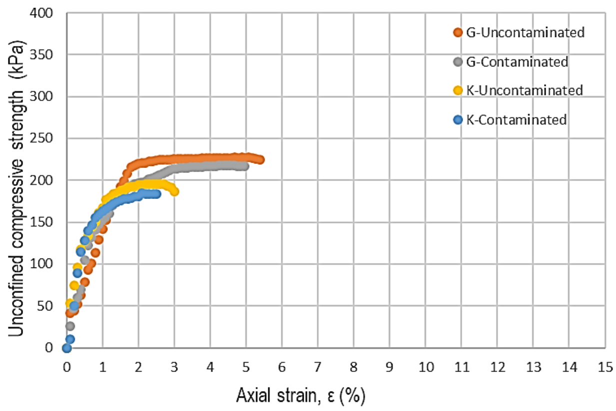

Figure 4. The effects of domestic wastewater on UCS of natural soils

4.1.5. Scanning Electron Microscope (SEM)

Scanning electron microscope (SEM) can be defined as an microscope that obtains images by scanning the sample surface. Therefore, SEM imaging was used to obtain information about the surface morphology of natural soil particles uncontaminated and contaminated by wastewater. Figure 5 and 6 show the morphology of natural soils at 20 µm diameter and 500x magnification. Figures can provide information on the proportion of large and small size pores and structure of particles in natural soils. Previous studies showed that wastewater and water flow rate can cause flocculation or dispersion in the microscopic structure of clays [18 and 23].

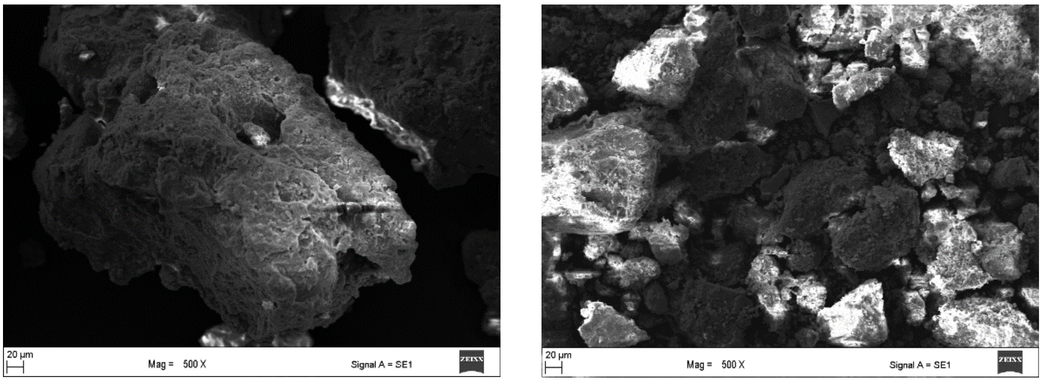

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Figure 5. Sem image of G natural soil (1) uncontaminated soil (2) contaminated soil

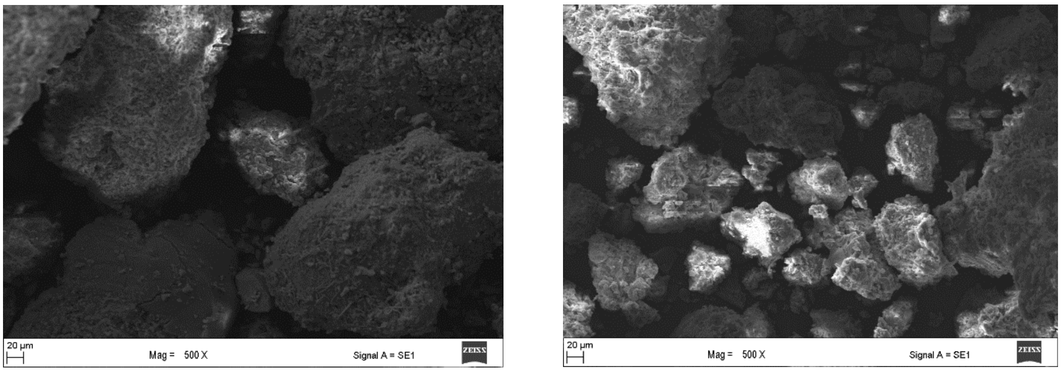

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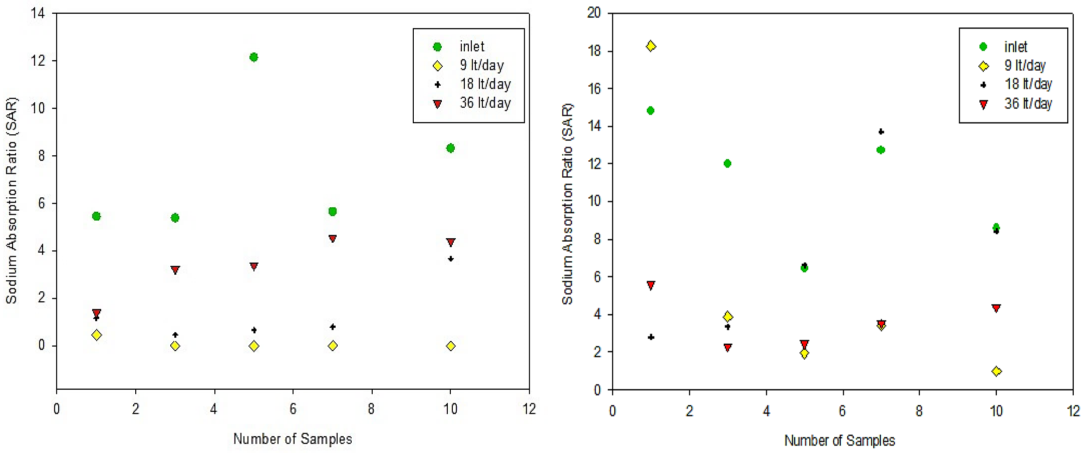
Figure 6. Sem image of K natural soil (1) uncontaminated soil (2) contaminated soil

4.2. Wastewater Treatment Performance of Natural Soils

4.2.1. Sodium Absorption Ratio (SAR)

The SAR can be seen as a simple parameter by which salt-affected soils can be determined when swelling clays are present [12]. The SAR was calculated as the ratio of Na (sodyum) concentration to the Ca(calcium) and Mg (magnesium) concentrations by the following formula.

$$\text{SAR} = \frac{\text{Na+}}{\sqrt{\frac{[\text{Ca+2}]+[\text{Mg+2}]}{2}}}\ (ppm) \qquad (1)$$



(1) (2)

Figure 7. (1) SAR filtration of soil G (2) SAR filtration of soil K

The SAR concentration in the inlet water of soil G is approximately 7.38 ppm. The SAR retained at approximately 99% in the column fed at 9lt/day hydraulic rate, where it retained 80% and 54%, in 18 and 36 lt/day soil-columns, respectively. The K soil stated a lower performance in terms of SAR retention rate compared to G soil. It is stated in the literature that Na and Ca concentration of soil may be affected by wastewater application [16]. It has been observed that this situation can cause significant changes in the physical structure of the soil [31].

4.2.2. Hardness

Hardness can be defined as a measure of calcium and magnesium dissolved in water. Generally, waters containing calcium carbonate below 75 mg/lt are considered as soft. Medium hard, hard and very hard waters are classified as 75-150, 150-300, 300 mg/lt and above, respectively. In this study, hardness was calculated by the following formula depending on the concentration of calcium and magnesium [14].

$$Total\ Hardness = [2{,}497\ x\ Ca^{+2}] + [4{,}118\ x\ Mg^{+2}]\ \text{(mg/lt)} \qquad (2)$$

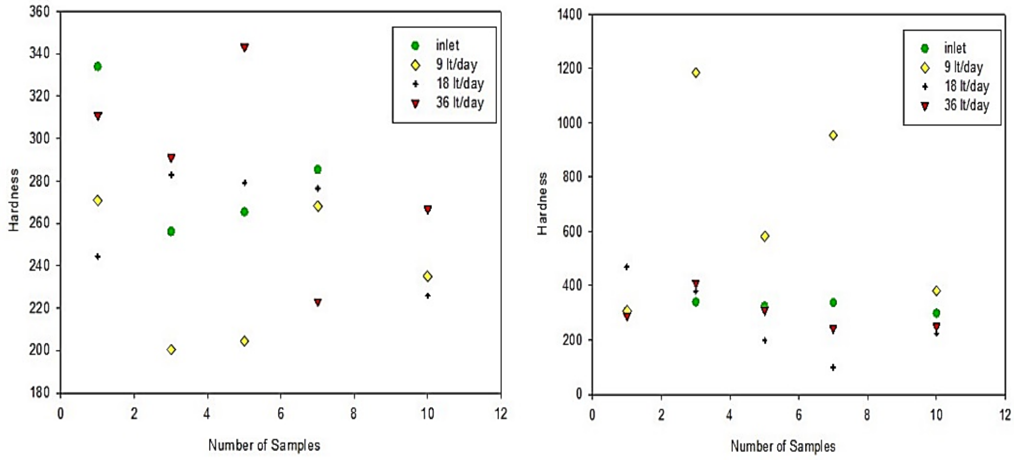


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Figure 8. (1)G soil filtration hardness (2)K soil filtration hardness

Hardness results are given in figure 8. While the hardness of the water varied between 200-350 mg/lt in the G soil-column, it varied between 100-1185 mg/lt in the K soil-column. The soil structure may contain substances that can be easily dissolved or decomposed [28].

4.2.3. Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is an important parameter used to determine the degree of pollution in water. It is usually expressed in mg/lt. As a result of natural soil filtration, COD values in wastewater are given in figure 9. COD values of wastewater with high pollution load in both soil-columns reduced to low levels. This case indicates a high level of COD retention in wastewater by soil. A previous study indicated a minimum of 60% COD can retention [24].

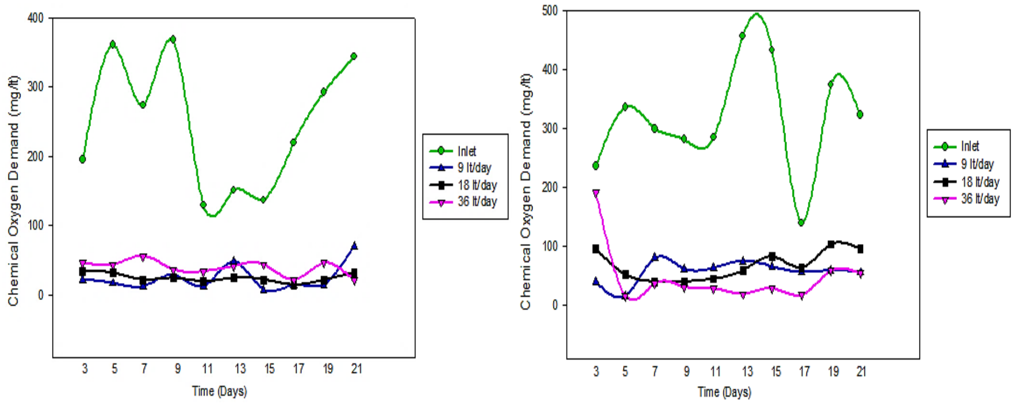

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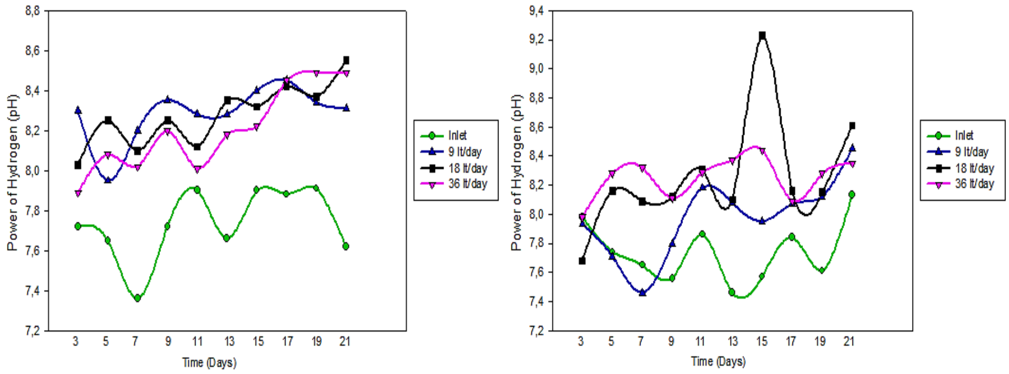
Figure 9. (1) COD removal of G soil-column (2) COD removal of K soil-column

4.2.4. pH Value

pH value can be a parameter in wastewater treatment that affects the living conditions of microorganisms and the functioning of chemical reactions. It is a measure that shows whether the water is acidic or basic. When Figure 10 (1) and (2) are examined, it is seen that the soil-column outlet water PH values varies between 7,98 and 8,29 at different hydraulic loading rates. According to the Wastewater Treatment Plant Technical Procedures Communiqué, it has been stated that the pH of the wastewater should be between 6-9 before being discharged to the receiving environment [29].

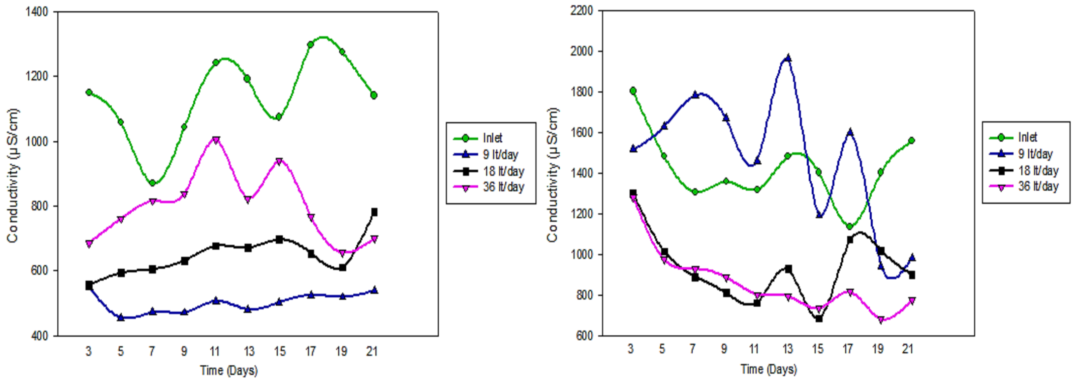


(1) (2)

Figure 10. (1) pH filtration of G soil-column (2) pH filtration of K soil-column

4.1.5. Conductivity

Conductivity is another parameter used in determining water quality. As the impurity in water increases, the conductivity of water increases. In other words, the higher the conductivity of water, the more water can contains a substance that is not water.



(1) (2)

Figure 11.(1) Conductivity filtration of G soil-column(2) Conductivity filtration of K soil-column

The conductivity value of a high quality water usually needs to be below 400 µS/cm. In order to be classified as slightly polluted water, it should not exceed 1000 µS/cm. Conductivity can reach high levels in polluted waters and in waters where a large amount of minerals are dissolved from soil [15]. When figure 11 is examined, it is observed that the average conductivity value of the G soil-column outlet waters is below 1000 µS/cm.

5. CONCLUSION AND RECOMMENDATIONS

Recently, a significant part of the population in all rural parts of the world relies on natural treatment systems for the treatment and disposal of wastewater [17]. These systems are accepted as a suitable option for wastewater treatment in terms of efficiency, economical and low energy use [30]. Therefore, this study was conducted in order to evaluate the removal of pollutants from water at different hydraulic loading rates and the impact of these pollutants on soil.

As a result of this study, it has been found that the pollution load of the wastewater entering the filtration (soil-column) environment is reduced. Comparing the inlet water and the soil-column outlet waters, the SAR retained at an average minimum efficiency of 50%. According to the hardness results, it was observed that the soil-column inlet and outlet water is in the 'hard' or 'very hard' class. The COD value was retained at a high rate by the soil. The pH and partial conductivity measurement results were also at acceptable levels. Different treatment efficiency results were reached in each column independent of soil structure. Wastewater analysis figured out that there is a relationship between the treatment of wastewater and the rate of hydraulic loading.

As another result of this study it was observed that the retention of pollutants in wastewater, the interaction of soil particles with pollutants and soil filtration can cause changes in some physical and mechanical properties of soil. In this regard, it may be recommended to define the soil-pollutant interaction before soils can be used for any purpose. Also, the performance of long-term natural wastewater treatment and filter environment can be evaluated.

NOTICE

This study is derived from an ongoing doctoral thesis (N.Baykus).

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