JANUARY 2021 Ph.D. in Civil Engineering NURDAN BAYKUŞ

HASAN KALYONCU UNIVERSITY

INSTITUTE OF NATURAL AND APPLIED SCIENCES

TREATMENT OF WASTEWATER BY INFILTRATION AND ITS EFFECT ON THE ENGINEERING PROPERTIES OF NATURAL SOILS

Ph.D. THESIS

IN

CIVIL ENGINEERING

NURDAN BAYKUŞ

JANUARY 2021

Treatment of Wastewater by Infiltration and Its Effect on The Engineering Properties of Natural Soils

Ph.D. Thesis

In

Civil Engineering

Hasan Kalyoncu University

Supervisor

Prof. Dr. Mehmet KARPUZCU

By

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January 2021

	GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES INSTITUTE **PhD ACCEPTANCE AND APPROVAL FORM**

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this study.

Nurdan BAYKUŞ

ABSTRACT

TREATMENT OF WASTEWATER BY INFILTRATION AND ITS EFFECT ON THE ENGINEERING PROPERTIES OF NATURAL SOILS

BAYKUŞ, Nurdan

Ph.D. in Civil Engineering

Supervisor : Prof. Dr. Mehmet KARPUZCU

January 2021, 169 pages

Recently, treatment and recovery of wastewater play an important role in the world. Generally, wastewater treatment involves collecting wastewater in a place transported by the central sewage system and treating wastewater according to its type. However, in rural settlements that do not have a central sewage system, the removal of wastewater can only be achieved with onsite treatment systems.

Soil takes an important part in onsite wastewater treatment. Soil can provide contaminants in the wastewater to be removed from the water. On the other hand, as is known wastewater contains many organic, inorganic substances and microscopic contaminants. As a result of the interaction of the soil with these contaminants, physical, chemical and mechanical properties may change. This change in soil structure can change the properties of the infiltration areas originally designed and thus it can also affect the efficiency of wastewater treatment. For this reason, the effects of onsite wastewater treatment systems on both wastewater treatment performances and geotechnical properties of natural soils were examined in this study.

Wastewater was treated with the infiltration areas developed by simulating with a natural soil column. Wastewater which was taken from the influent water of GASKI Kızılhisar Wastewater Treatment Plant was first passed through the pre-sedimentation tank and then leaked into the soils in the plexiglass pipe with a diameter of 20 cm and a height of 100 cm. Natural soils were taken from 4 different types of field conditions were used for filtration. Columns were constructed for each soil type with different hydraulic loading rates by 9, 18 and 36 L/day. These columns were fed with continuous flow for 23 days.

Laboratory and field-scale studies were conducted to determine the properties of natural soils and wastewater before and after leakage. The results of these studies indicated that while soil filtration improves wastewater quality, it can change the engineering properties of soils.

Key Words: Soil Filtration, Wastewater Treatment, Geotechnical Survey, Water Quality, Soil Structure.

ÖZET

Atıksuların İnfiltrasyonla Arıtılması ve İnfiltrasyonun Doğal Zeminlerin Mühendislik Özelliklerine Etkisi

BAYKUŞ, Nurdan

Doktora Tezi, İnşaat Mühendisliği

Tez Yöneticisi : Prof. Dr. Mehmet KARPUZCU

Ocak 2021, 169 sayfa

Günümüzde atık suların arıtılması ve geri kazanılması önemli bir amaç olarak gündeme gelmektedir. Genellikle atık su arıtımı, atık suyun merkezi kanalizasyon sistemi ile taşınan bir yerde toplanması ve atık suyun çeşidine göre arıtma işlemine tabi tutulmasını içerir. Fakat merkezi kanalizasyon sistemi olmayan kırsal yerleşim alanlarında, atık suların zararsızca uzaklaştırılması ancak yerinde arıtma sistemleri ile sağlanabilmektedir.

Zemin, yerinde atık su iyileştirme sisteminde önemli bir role sahiptir. Zemin, atık su içindeki kirletici maddelerin sudan uzaklaştırılmasına olanak sağlamaktadır. Ancak bilindiği üzere atık sular çok sayıda organik ve inorganik madde ve çok sayıda mikroskopik kirleticileri içermektedir. Zeminin bu kirleticilerle etkileşimi sonucunda fiziksel, kimyasal ve mekanik özellikleri değişebilmektedir. Zemin yapısındaki bu değişim başlangıçta tasarlanan infiltrasyon alanların özelliklerini değiştirebilir ve dolayısıyla atık su arıtma verimliliğini de etkileyebilir. Bu sebeple, bu tez çalışmasında yerinde atık su iyileştirme sistemlerinin hem atık su arıtım performansları hem de doğal zeminlerin geoteknik özellikleri üzerindeki etkileri incelenmiştir.

Doğal zemin kolonu ile simule ederek geliştirilen infiltrasyon alanları ile atık suların arıtılması sağlanmıştır. GASKİ Kızılhisar Atıksu Arıtma Tesisi giriş suyundan alınan atık sular önce ön sedimentasyon tankından geçirilmiş ve daha sonra 20 cm çapında ve 100 cm yüksekliğinde olan pleksiglas boru içerisindeki zeminlere sızdırılmıştır. Filtrasyonda, dört farklı tipte, arazi koşullarından alınan doğal zeminler kullanılmıştır.

Her bir zemin tipi için 9, 18 ve 36 L/gün hidrolik yükleme oranlarında kolonlar oluşturulmuştur. Bu kolonlar 23 gün boyunca kesintisiz akışla beslenmiştir.

Doğal zeminlerin ve atık suların sızıntı öncesi ve sonrası özelliklerini belirlemek için laboratuvar ve saha ölçekli çalışmalar yapılmıştır. Bu çalışmaların sonucu, filtrasyonun atık su kalitesini iyileştirmede ve zeminlerin mühendislik özellikleri üzerinde etkili olabileceğini göstermiştir.

Anahtar Kelimeler: Zemin Filtrasyonu, Atıksu Arıtımı, Geoteknik Etüt, Su Kalitesi, Zemin Yapısı.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my supervisor Prof. Dr. Mehmet KARPUZCU for his continuous encouragement, advice, recommendations, criticisms and generous guidance offered during this study.

I would like to thank Prof. Dr. Hanifi ÇANAKÇI for his guided positive and constructive criticisms of this study. I would like to thank Prof. Dr. Aytaç GÜVEN for his advice, valuable discussions and recommendations on various aspects of this study.

I would like to thank Asst. Prof. Dr. Adem YURTSEVER for his patiently and sincerely answering all my questions, assistance and critical review of this study. I would also like to thank my jury member Asst. Prof. Dr. Muhammet ÇINAR for his comments and suggestions in the formation of this study.

I would like to thank GASKI Kızılhisar Wastewater Treatment Plant İbrahim ÇELİK and his team for their technical assistance and support from the beginning to the end of my field study. I would like to thank my colleague Res. Asst. Beyza ÖZPALAS for her constant support, motivation and helping read and review of this study. I would also like to thank everyone who contributed to the preparation during my studies.

I would also like to express thanks with the deepest feelings Asst. Prof. Dr. Cevdet Emin EKİNCİ who was directly or indirectly involved in the process of this study.

And my parents… I sincerely thanks to their endless faith and trust in me. I dedicate this study to them.

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LIST OF SYMBOLS/ABBREVIATIONS

A	Adıyaman/Turkey
ABR	Anaerobic baffled reactor
ASTM	American Society for Testing and Materials
BC	Bentonite clay
BGW	Brackish groundwater
BOD	Biochemical oxygen demand
c	Cohesion
CBR	California bearing ratio
C_c	Compression index of soil
CSF	Composite soil filling
CH	High plasticity clay
CL	Low plasticity clay
CSF	Constructed soil filter
COD	Chemical oxygen demand
C_v	Coefficient of consolidation
DOC	Dissolved organic carbon
EC	Electrical conductivity
EWQI	Entropy weighted water quality index
G	Gaziantep/Turkey
GASKI	Gaziantep Water and Sewerage Administration
G_s	Specific gravity
HLR	Hydraulic loading rate
k	Permeability

K	Kilis/Turkey
K_h	Hydraulic conductivity
K_{sat}	Saturated hydraulic conductivity
LL	Liquid limit
LCA	Life cycle assessment
LCC	Life cycle costing
MBR	Membrane bioreactor
MICP	Microbiologically induced carbonate precipitate
MSW	Municipal solid waste
n	Porosity
OWTS	Onsite wastewater treatment systems
pH	Power of hydrogen
PI	Plasticity index
PL	Plastic limit
PVC	Polyvinyl chloride
q_u	Unconfined compressive strength
SAR	Sodium absorption rate
SEM	Scanning electron microscopy
SS	Suspended solids
SWIS	Subsurface wastewater infiltration system
TDS	Total dissolved solids
TDW	Treated domestic wastewater
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TOC	Total organic carbon

TP	Total phosphorus
TURKSTAT	Turkish Statistical Institute
TWW	Treated wastewater
UCS	Unconfined compressive strength
USCS	Unified Soil Classification System
USSLS	The United States Salinity Laboratory Staff diagram
V	Total volume
W	Total weight
WHO	World Health Organization
ω_{opt}	Optimum water content
Ş	Şanlıurfa/Turkey
φ	Internal friction angle
σ	Stress
ε	Strain
γ_k	Dry density of soil
γ_{kmax}	Maximum dry density
γ_n	Bulk density of soil
γ_w	Specific weight of water

CHAPTER 1

INTRODUCTION

1.1 General

It is clear that ecosystem and natural resources are not inexhaustible. Water is the most valuable natural resource in the world. Because water is the most essential element needed for living things to survive and is an indispensable element of human nature. Seventy five percent of our world is covered with water but only 2.5% of these water are freshwater. Environmental pollution, the rapid increase of population and the increase in demand for water cause the amount of fresh water to decrease further. This state poses a very significant problem worldwide and our basic problem is not that it is no water in the world but that it is insufficient of sweet or drinkable water that can be used. For this reason, countries have focused on reducing the need for fresh water resources and developing savings and precaution that can help conservation activities.

Nowadays, the reuse of treated wastewater has become a viable option to minimize the need for water resources. In this way, it is possible that water can be returned directly or indirectly to water cycle with minimal environmental problem.

Generally, wastewater treatment involves the collection of wastewater in a location transported by the central sewage system and treatment of wastewater according to its type. However, in some rural settlement areas without a central sewerage system, network construction of the central sewerage system can not possible and the harmless removal of wastewater can only be achieved by individual structures. Natural treatment methods are shown in Figure 1.1 can be applied for the removal of wastewater in rural area.

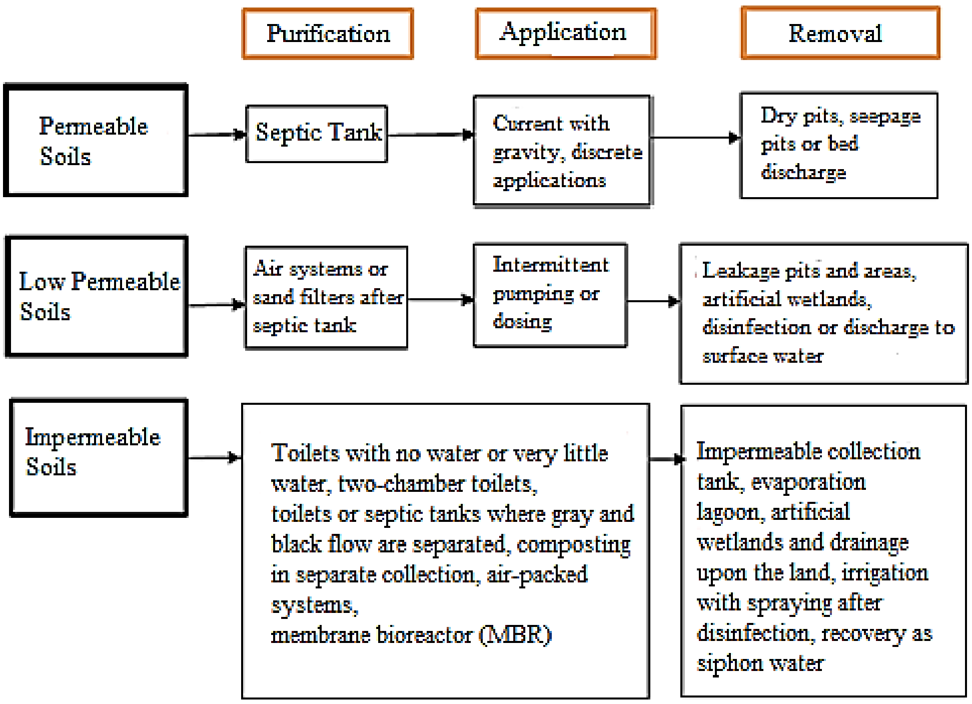


Figure 1.1 Wastewater treatment and disposal systems according to soil groups (e-Legislation no: 13873).

Natural treatments can be the most ideal systems for villages, individual houses away from each other, hotels, resorts and sites. In addition, wastewater from house can be collected by simple developed septic tank systems. After that, it can be hold in the tank for a certain period of time in order to separate solids and liquids then the filter field, land application, land discharge and surface water discharge alternatives can be applied for the natural treatment of wastewater. These alternatives can a suitable option for pre-treatment of wastewater and it can provide additional benefits to reusing water.

Recently, the method of onsite intervention for wastewater treatment and disposal is common in all rural areas of the world. A significant proportion of the population in any country relies fully onsite system for the treatment and disposal of domestic wastewater. For example, approximately 13% (more than 2 million people) of the Australian population do not have a sewage system (Thomas et. al., 1997). In addition, approximately 25% of the United States does not exist sewerage networks (Dawes and Goonetilleke, 2003; Cooper, 2016). According to 2016 TURKSTAT data approximately 15.8% of our country's population does not have sewerage networks. Natural treatment methods are one of the most efficient and sustainable ways of wastewater treatment in these areas. Naturally large amounts of water regeneration can be achieved with built wetlands. In another way, it is nature's assignment to remove the pollutants from water by soil acting as a filter. Soil is an excellent environment for removing pollutants in wastewater (Dawes and Goonetilleke, 2003). However, understanding the ability to accept, process and distribute wastewater into depending on the structure of a soil is very important in the selection and management of wastewater treatment systems in field (Carroll et. al., 2006).

The structure of a soil, soil porosity, soil physical, chemical and mineralogical properties, grain distribution size, permeability of soil, soil colour, bulk density, infiltration etc can be associated with many properties. However, there are many properties that distinguish one soil from another. Explaining the structure and different physical properties of soils used for many different purposes from agriculture to engineering structures has a dominant role (Balasubramanian, 2017). A good soil structure can also vary according to the purpose of necessity.

Johannes et. al. (2017) stated that the loss in structural quality of soil may be due to mechanical stresses created by tillage methods and which may result in the loss of hydrostructural stability of the soil and structural collapses. In their study, they concluded that soils with generally good structural quality contained more than 20% clay.

It is not possible to use an impermeable soil as a filter area. Leakage method should not be considered or more complex treatment systems should be preferred where in soils with very low permeability, groundwater level is high, overflows and erosion occur and wastewater is close to water sources.

Soil properties can change directly or indirectly when the soil's equilibrium structure in nature interacts with organic and inorganic pollutants caused by environmental conditions, applying different physical, chemical or biological methods to soil, compacting or excavating the soil under any load (Mohamed and Antia, 1998). Because physical and index properties of soils, stress-strain relations, bearing strength, stability, hydraulic conductivity, shear strength parameters and geological properties are of great importance in engineering studies. Many of these properties can affect each other (Phogat, 2015). For example, the strength characteristics of soil depend mainly on the physical properties of soil.

Cyrus et. al. (2010) stated that changing the mechanical properties of soils due to chemical pollution constitutes an important environmental problem in the field of geotechnical engineering. They mentioned on structural damage in buildings on soils contaminated by various chemical pollutants and emphasized the importance of this problem. These structural damages can generally be caused by the impact of different settlements, not from the lack of bearing strength.

The more water a clayey soil absorbs, the more swells and volume increases. 10% expansion as volumetric of clays can be possible (Chen, 1988). However, when it dries, it shrinks so much. Swelling and shrinkage behavior shows a high rate of change with the change in water content in soils containing smectite clay group. The effects of this change can also be serious. Because swelling and shrinkage are not completely recycling, that is, classical elastic or plastic theory behavior does not exhibit (Mokhtari and Dehghani, 2012; Khademi and Budiman, 2016).

Generally, as the amount of minerals found in soil increases, the expansion potential of soil increases. Soils with swelling-shrinkage potential are significantly under control as long as the existing water contents remain relatively constant. It don't usually cause a problem (Jones and Jefferson, 2012).

Edil and Fox (2000) stated that removing strong acid or alkaline solutions with particles containing minerals could pose an environmental problem. Particles with high mineral content due to leakage effect can change of physical properties by interacting with chemical substances. For example, some soil elements are displaced in acid leach and the montmorillonite clay in soil can be transformed into kaolinite. In another study, the structural formation and strength of soil have been shown to be related to biological activities, different organic waste type and density and even various ecological parameters (Horn et. al., 1994).

Mortezaei and Karimpour-Fard (2017) stated that clay soils are both the most widely used material in waterproofing and also play an important role in waste and pollution control. They emphasized that the permeability of soils is a key parameter and should be carefully determined to ensure that the soil performs well.

Akhtar (2012) stated that a large amount of leakage flows could move solids in soil and form a pipe or channel in soil. In addition, even if the leakage flow rate is very small, being able to create a large amount of pore pressures in soil can reduce the stability of soil. The exact evaluation of strength parameters of a soil depends on the determination of the leakage and permeability properties of soil. The more permeable the soil, that is, if it consists of porous layers, the greater leakage.

Ghosh (2013) stated that as the water content of soil increases, cohesion decreases with the clay grains diverge from each other and therefore shear failure occurs in soil. Generally, cohesion increases until water content reaches the ω_{opt} and cohesion (c) and internal friction angle (φ) decreases in water contents after the ω_{opt}.

1.2 The Aim of the Study

In recent century, the demand of water is increasing gradually all over the world. However, it is known that water resources are exhausted rapidly. Nowadays, treatment and recovery of wastewater have become an important purpose in order to protect limtied clean water resources. Not only higher quality treated water but also greater amounts of recycled water are needed.

Natural storage of groundwater is difficult and slow. The groundwater consumption rate is much larger and faster than the re-storage rate. In this respect, artificial storage of groundwater is becoming important. The oldest and simplest artificial storage method is infiltration.

Currently, the effective and low cost subsurface wastewater infiltration systems (SWIS) (e.g., septic tank, biological contractor and biological filtration) are being developed for wastewater disposal and wastewater treatment in small communities and rural areas.

The treatment of domestic wastewater passed from pre-sedimentation pond (septic tanks) by giving natural soil was researched in this study. It is aimed to contribute to sustainability of water resources and recovery of wastewater by utilizing the treatment capacity of soil. In addition, it provides to reduce the cost of wastewater recovery and natural storage of underground water resources. Fine grain soils are thought to can be effective in removing organic and inorganic pollutants in wastewater, as it tend to change of natural stabilizations.

Soils are a natural material that can show different properties at almost every point. The properties of soils are definitely affected by land use, current activities in field, natural and unnatural resources. Leakage of wastewater into soil is different from potable water (tap water). Viscosity, chemical composition, heat, etc of wastewater can affect the permeability of soils. These factors can affect implicitly the entire mechanical stability of soil. There is an important correlation between atterberg limits, water content, permeability, void ratio, compaction and strength on fine grained soils with high water retention capacity. For this reason, it is aimed to define the behavior of soil in different conditions and to promote the right applications in short and long term of soil survey.

This study provides the determination of the treatment performance of wastewater. Morover, it explains the impact of soil which is used for leaking of wastewater on engineering properties.

1.3 Organization of the Thesis

Chapter 1 - Introduction, general descriptions and explanatory studies, the aim of the study.

Chapter 2 - Literature review, presents the previous studies, findings and comments on the research topic and literature summary.

Chapter 3 - Materials and methods, study areas, experimental study procedures and limitations of the study are given.

Chapter 4 - Experimental findings and interpretations, wastewater and soil analyses.

Chapter 5 - Conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The main objective of this section is to define the resources related to our study subject and to investigate whether the study has been researched before and to identify the deficiencies and limitations of similar studies. For this purpose, it provides to investigate, examine, classify, summarize and analyze the sources related with the study.

2.2 Rural Sewage Treatment Systems and Applications

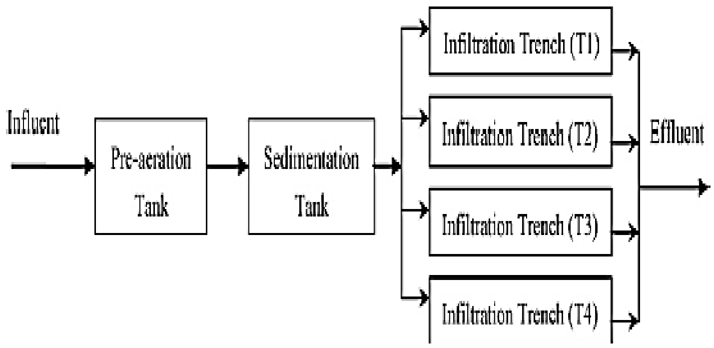
Dawes and Goonetilleke (2003) conducted an investigation on the role of site and soil characteristics in onsite sewage treatment. In this study that 16 different of sites with septic tanks and underground wastewater disposal sites were investigated effects of performance and characteristics of soil on wastewater treatment. As a result of study, the regeneration capacity of wastewater which varies with the density was found to be directly related with local soil conditions.

Qu et. al. (2012) investigated problems in rural sewage treatment and measures to be taken. In their work, they aimed at the long-term operation of rural sewage treatment systems, improving the water environment in rural areas and protecting ecological environment in rural areas. They also addressed mistakes in selection of sewage treatment systems in rural areas, administrative and political problems, financial resource problems and poor environmental awareness affecting sewage works. Due to the lack of wastewater treatment technology in rural areas, more than 90% of sewage is discharged directly into rivers or lakes without any treatment (Zhan et. al., 2010).

Generally, a large budget may be required to establish wastewater treatment plants (Moral Pajares, 2019). In this respect, it can necessary to develop reasonable waste sewage treatment technologies in rural sewage treatment, to regulate and establish these technologies with a long and effective management mechanism as well as to develop sustainable environmental awareness for the solution of rural sewage treatment plant.

Li et. al. (2012) conducted an investigation on the use of a subsurface infiltration system in treating campus sewage under variable loading rate. They investigated that relationship domestic wastewater treatment with hydraulic loading rate (HLR) between January-August 2010 as daily and seasonal in pilot-scale SWIS applications. As a result of study showed that the operating performance of the SWIS was robust in terms of obtaining high quality treated water although HLR was variable. Efficiency in removing contaminants decreased as loading rates increased. Therefore, they mentioned that SWIS technologies are a more suitable method for places that can support land demand, such as campus and rural areas.

Zhang et. al. (2007) conducted that land and laboratory studies to investigate the effect removal of wastewater in shallow soil infiltration treatment (SSIT).



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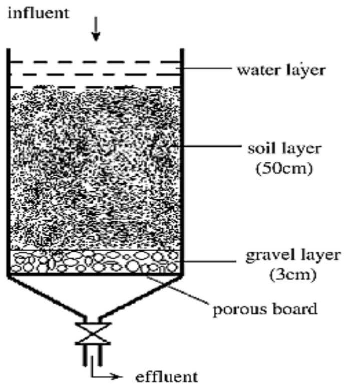


(2)

Figure 2.1 (1) Schematic flowchart of the SSIT system (2) Bench-scale soil column (Zhang et. al., 2007).

They presented that in SIT (SIT, with effective depth 0.3 m) systems organic matter was removed efficiently. They also noted that temperature and HLR are the two most important factors affecting the removal of chemical oxygen demand (COD) and organic pollutants.

Chun et. al. (2008) designed two-stage anaerobic tank and soil trench system with a view to evaluate soil infiltration technology in places without a central wastewater treatment plant. The system was created by taking wastewater from raw sewage of dormitory building with a population of 1000-1200 people which under ecological grass around dormitory building. Raw sewage water was kept in anaerobic tank during retention time of 24 hour. As a result of this study, it was found that can be reduced COD by 89-96%, suspended solids (SS) by 91-97%, and total phosphorus (TP) by 91-97%. In addition, it was found that total nitrogen (TN) and ammonium (NH_4^+) can be removed by 68% -75% and 96% -99% respectively.

Zhang et. al. (2005) noted that SWIS improves nitrogen removal of wastewater. They built a underground leak system of 3.0 m long, 3.0 m wide and 0.8 m deep in a village which located in China/Dianchi Valley. This area filled with a 25% slag mixture of red clay. The treated wastewater was collected through collection pipes under the system in the system fed by rural area sewage. TN and TP adsorption capacities of soil in infiltration system were determined. Nitrogen removal was successfully achieved in this system filled with low permeability red clay. Ammonium (NH_4^+) removal rate was found over 90%

Yang et. al. (2016) investigated the effect of HLR on contaminant removal efficiency in SWIS. Pilot SWIS was a leak-proof cement pool with a volume of 1.5 m^3. The inside of the pool is filled with 11 layers of filter material. The SWIS was operated under two different HLR of 0.2 and 0.5 m^3/m^2d. When HLR was 0.5 m^3/m^2d, it was found that the total organic carbon (TOC), COD and NH_4^+ removal rate was more than 85% and the TN removal rate was less than 20%. While contaminant removal efficiency increased slightly at 0.2 m^3/m^2d in HLR, TN removal rate decreased.

Gao et. al. (2012) investigated treatment of domestic sewage water in anaerobic baffled reactor (ABR), composite soil filling (CSF) and free water surface (FWS) systems in China rural areas. As a result of this study, the concentration of the system's effluent water was found to meet China's (GB18918-2002) 1B level integrated wastewater discharge standard. Plants in FWS have helped to improve purifying property of the system. Since these systems have zero energy consumption, superior wastewater treatment quality, low investment and operating costs. Therefore, they stated that can be used widely in rural areas, tourist areas, service areas.

Yi et. al. (2007) examined some renovated technologies which including natural treatment systems, anaerobic biological treatment, biofilm reactors and wastewater reclamation technologies for water pollution control in China. Wastewater treatment efficiency of the applications showed differences by each other. For example, turbidity and bacteria removal rate was possible high in a system where COD removal rate is low. In the study, they stated that in order to keep the COD concentration in wastewater under appropriate values in different systems, ventilation or retention time of wastewater may increase or decrease.

Wang et. al. (2016) examined septic tank, stabilization pond process, land treatment system, activated sludge method and biological membrane technologies applied for the treatment and disposal of wastewater in China. The results of their study are as follows.

- Septic tanks could reduce more than 70% of suspended solids content and 30% of biochemical oxygen demand (BOD_5) but it has prohibited to apply because discharge cannot provide water quality in some countries.

- Land could be fully utilized in implementation of stabilization pools but this covers a wide area and wastewater treatment effect varies depending on the climate conditions. It may not be suitable for application in cold climate regions.
- Wastewater land treatment system has a simple structure and costs only 10-50% of conventional methods (Shen and Wang, 1999). This method could have unique advantages for small-scale domestic sewage treatment and it could be made full use of natural conditions.
- Activated sludge method and biological membrane could be used in areas where population scale is less than (<1000 population equivalent). A different study stated that membranes have predictably stable product water quality and membrane application can be improved or developed by using new inert material (Soellner, 2002).

Commonly used method for disposal of domestic wastewater in China is biological treatment (Chen et. al., 2005). Biological treatment plants can be low in cost and provide immediate benefits. But increasing population and lifestyle changes may require development of new methods within limits of legislation and provision of combinations of existing methods.

Chen et. al. (2018) studied on industrial wastewater treatment technology and prospect. They mentioned that in development and improvement of sewage treatment technologies, more new results could be obtained and more efficient discharge standards could be achieved. They emphasized urgency and importance of wastewater treatment.

Wang et. al. (2017) stated that rural water pollution control is a complex project involving the interests of government, district businesses, farmers. These stakeholders may need to better coordinate their own interests to solve water pollution and problem in rural areas. They also stated that free of problem progress of water pollution control in rural areas need relevant policies and measures.

Carroll et. al. (2006) investigated onsite wastewater treatment systems (OWTS) where places central wastewater collection and treatment systems not available. The majority of Gold Coast region/Australia (over 15000) has a septic tank or soil adsorption system. However, researchs carried out in the Gold Coast region have shown that septic tank-soil adsorption systems do not appropriate standards accepted by the local government of approximately 90% of wastewater treatment performances (Goonetilleke et. al., 2002).

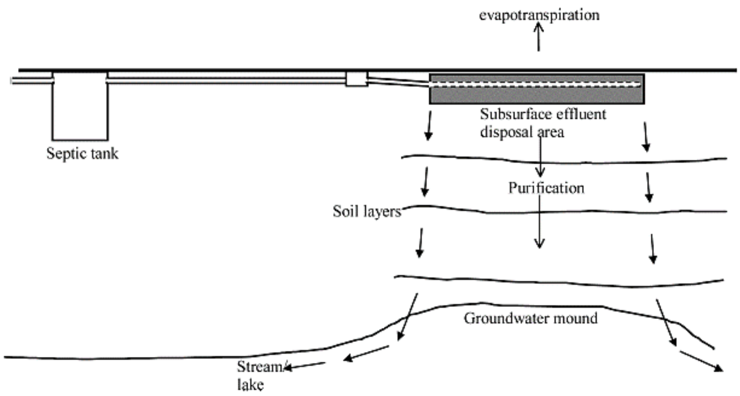


Figure 2.2 Distribution area and groundwater system of OWTS wastewater treatment system (Carroll et. al., 2006).

Failure of an OWTS can indicate that any of treatment stages shown in Figure 2.2 have failed. However, rather than natural defects in system technology, unsuitable positioning (inadequate soil and field conditions) also design problems or their operation and management could be related with it (Otis and Anderson, 1994; Carroll et. al., 2004). In their study, they stated that in order to reduce this negative effects, it was necessary to develop a more robust methodology to achieve sustainable onsite wastewater treatment that would not harm the environment and public health.

Thomas (2009) aimed to develop flexible design methodology for places without a central sewage system that could maximize treatment goals by using principles of most widely used systems.

Morales (2015) investigated what extent to microbial pathogen (virus and bacteria) removal in OWTS was affected by soil structure and depth. Sand, sandy loam and clay loam soil in study were used. He stated all soil types had microbial pathogen removal rates 99.99% at 25 cm depth. In addition, a numerical modeling developed with bacteria and virus test data demonstrated consistency with experimental data at all depths of three soil types. In the study, it was stated that OWTS performance could be affected by climate change and HLR. Also, small pores in fine-grained soils was stated to be more effective than coarse-grained porous soils in filtration. It has been observed that unsaturated soils tend to retain more germs than saturated soils, that is, bacteria and viruses are more retained in soil with reduced water content (Morales et. al., 2014).

Li et. al. (2015) investigated effect of SWIS used in domestic wastewater treatment on contaminant removal rates different HLR. They used a substructure that was mixed evenly in volume ratios, consisting of 5% activated sludge, 65% organic soil and 30% coal slag. When experiments increased average HLR to 12 cm/d, blockage was observed in layers SWIS due to excessive flow of sewage and permeability rapidly decreased to a small value. So as HLR increases, contaminant removal rate has decreased. More than 80% of contaminants in SWIS have been removed after pre-treatment under an appropriate HLR. In analyses of water quality received was stated that SWIS could have little negative impact on nearby stream.

2.3 Groundwater, Infiltration and Control

Wu et. al. (2018) carried out studies to characterize groundwater quality used for drinking purposes and to determine seasonal variability of groundwater quality. Hydrogeochemical assessment and entropy weighted water quality index (EWQI) have been used to evaluate the groundwater quality and its made measurement sodium (Na^+), sulfate (SO_4^{2-}), flüoride (F^-) and total dissolved solids (TDS) concentrations. This four hydrochemical parameters revealed that the groundwater quality improves but the influential factors do not change with the seasonal variation. These parameters contributed to the low groundwater quality respectively Na^+ > TDS > SO_4^{2-} > F^-. Groundwater in the research area has indicated as primary water source which used for irrigation and domestic purposes. However, according to the classifications defined by EWQI classified as ‘low’ or ‘very low quality water’ which is not suitable for drinking purposes.

Groundwater is the most important natural resource used for drinking especially in arid and semi-arid areas. Sadat-Noori et. al. (2013) collected and analyzed total of 58 groundwater samples. Over 65% of the water samples entered the category within the ‘poor’, ‘very poor’ and ‘unsuitable for drinking’ according to the Water Quality Index (WQI) assessment. Amiri et. al. (2014) investigated that fifty-nine groundwater samples studied the groundwater quality and suitability. Calculation of entropy weighted water quality index (EWQI) for groundwater samples have been evaluated

World Health Organization (WHO) and Iranian standards for drinking water. As a result of the study shown that the groundwater samples were in the 'excellent' to 'medium' quality class.

In a study in which effects of industrial wastewater on groundwater and soil quality have investigated, they have been tried to determine amount of heavy metals in both groundwater and soil profile (Bharti et. al., 2013). Consequently, it was expressed that industrial wastewater containing varying amounts of contaminants will may cause an increase in the concentration of heavy metals in groundwater and soil. It has been stated in different studies that surface water is affected by industrial wastewater with high COD concentration. It has been stated that surface water pollution especially in industrial development areas is significantly reduced and groundwater quality in these areas can be severely contaminated in terms of heavy metal concentration. For this reason, it was obseved that level of contamination in groundwater is not suitable for human consumption (Gagan et. al., 2016).

Groundwater can main source of water in many cities around the world. Groundwater evacuation in China is stated approximately 1/3 of urban water demand. Groundwater use in many European countries exceeds 70% of total water consumption, especially for domestic drinking water use. Excessive groundwater use negatively is able affects environment and can destroy urban groundwater resources. For example, while lowest groundwater table in Suzhou was 3 m of the 1930s, it has decreased to 68.7 m in 1995. The current demand may exceed natural charge and causing decreases in this way. Good organization and strong support from governments are needed to prevent exploitation of groundwater. In particular, use of deep groundwater provides a waste of high quality resources (Jago-ona et. al., 2008; XiaoZhao et. al., 2016).

The most important among the factors that cause groundwater pollution is direct discharge of wastewater that has not undergone treatment to receiving environments. Wastewater must be subjected to a some treatment process before being discharged to any receiving environment. In this way, it is be possible to use treated wastewater in land and to remove pollution. However, as well as the suitability for limit values in terms of physical, chemical and biological parameters of wastewater, soil characteristics of region should be taken into account. A receiving environment with suitable soil characteristics can provide wastewater treatment with required degree of treatment and even better quality (Şahin et. al., 2011).

Environment, human health, economic development and social prosperity can be affected severely contaminated groundwater and poor quality. Groundwater pollution control and treatment measures must be provided (Milovanovic, 2007).

Richards et. al. (2016) noted that discharge of septic tanks directly into surface water or groundwater could pose a risk. They showed that factors such as the condition of septic tank, the retention time of wastewater in tank, the management of tank and the number of tank users significantly can affect discharge water quality. In addition, they stated that discharge of domestic wastewater by subjecting to additional processes would be more beneficial in maintaining and improving water quality. Phillips et. al. (2015) and Yang et. al. (2017) stated that direct discharges of septic systems could be an important source of micro-pollutants for shallow groundwater and surface water systems.

Dirckx et. al. (2016) conducted a study to explain the potential of groundwater infiltration in dilution of wastewater. Working area was formed on a local scale of Flanders, Belgium. Observation wells were opened to monitor shallow groundwater level in the study area. These observation wells provided an easy understanding of possibility of leakage of groundwater into sewer. As a result of study, leakage from leaking sewers into groundwater have represent a significant part of total amount of wastewater dilution.

Another study in measurement of groundwater seepage and surface water inlets (I/I) were based on a model approach optimized for urban sewage system (Karpf and Krebs, 2011). Many information about I/I flows and temporal changes, determination of the of amount of I/I components, seepage potential of sewage pipes, past and future hydrological scenarios, properties of infiltration could be estimated with this model approach. For example, it has been determined that there is a relationship between seepage potential and pipe condition of sewage system. I/I can significantly affect the costs and operation of sewage system and wastewater treatment plants. It can reduce wastewater treatment efficiency and potentially can cause deterioration of water in the receiving environment. In addition, groundwater seepage can lead to deterioration of urban infrastructure, rapid aging of sewer pipes and deterioration of filling materials around of pipe leakages. In this respect, model approaches may be important to eliminate some negative effects.

Ellis (2001) stated that I/I poses a very significant problem worldwide. He explained that effective field controls and sustainable best urban drainage systems should be provided as a solution. On the other hand, many studies should be needed to express of sewage wastewater as potential source of groundwater pollution.

Das and Das (2003) investigated impact of food processing industry and septic tank wastewater on soil and groundwater. It has been analysed pH, electrical conductivity (EC), nitrate, chloride, sulphate, and phosphate for soil samples. Also, it has been analysed parameters like, pH, nitrate, chloride, sulphate, phosphate, BOD_5 and COD for groundwater. Results have shown that discharge of wastewater in land may reduces effectively contaminants due to adsorption and chemical reaction in soil. Septic tanks to prevent pollution of groundwater have been efficiency of treatment wastewater when selection properly underground drainage system.

Candela et. al. (2007) evaluated the soil and groundwater impacts of a golf course irrigated with treated wastewater of urban origin. They have took samples from the wastewater treatment plant, groundwater and soil profiles in different months to determine whether soil and aquifer under the golf course were affected by this type of water use. As a result of this study, they stated that hardness in groundwater and salinity rate in first 50 cm of soil increased due to cationic change in unsaturated zone. Microbiological risk was not observed due to effective soil filtration in aquifer.

2.4 Environmental Geotechnics and Sustainability

Ling et. al. (2016) conducted a case study on soil rapidy infiltration for emergy analysis of wastewater treatment systems in rural areas without a central sewage system. Emergy Analysis is a scale that provides economic statistics and energy analysis for purpose of assessing sustainability of systems. As a result of study has stated that rural sewage treatment systems will be provide 2.17E+18 sej·year economic benefits when converted to solar energy. It has also been stated that treated water can be used for direct irrigation, rural greening, etc and 73000 m^3 of water can be saved every year. In this study has been mentioned that these systems have low environmental impact and high conversion capacity and therefore will contribute to it sustainable development provided that it environmental, economic and social benefits are used depending on local conditions.

Basu et. al. (2013) investigated the relationship of different research and case studies in geotechnical engineering to sustainable development. As a result of researches, they stated that recent research on geosustainability is generally based on common sustainability concepts such as recycling, reuse and use of alternative materials, technology and resources. Additionally, geotechnical processes and products can need to have a life cycle for any geo-sustainability assessment framework. It has suggested that these approaches should be developed and evaluated using criteria analyses and combinations such as Life Cycle Costing (LCC) and Life Cycle Assessment (LCA).

Shackelford (2014) stated that dispersion or diffusion of pollutants was important in field of environmental geotechnics. Diffusion spreads towards from more dense concentration to less dense concentration (Shackelford, 2013). This spread is an important process in assessment of pollutant migration through low permeability barriers especially in waste applications. Diffusion may depend on factors which aqueous phase concentration, saturated and unsaturated properties, dry density of solid mass, porosity, hydraulic conductivity or permeability coefficient, magnitude of leakage rate, time, etc.

The mass flow dissolved in underground soil can be significantly reduced by the reduction of k_h, in other words, while k_h value of underground soil is high, the size of polluting migration can be said to be high. Low permeability and hydraulic conductivity values can be important in terms of contaminant transport and contaminant retention time (McDowell- Boyer et. al., 1986).

XiaoZhao et. al. (2016) emphasized importance of urban underground resources in sustainable development. Worldwide urban planning is carried out in a demand-driven ‘top-down’ way but it should be known that there are many valuable resources in the urban underground. In this study was stated that the existence of natural resources should be included in planning and the "bottom-up" thinking should be adopted. Urban underground contains not only construction site, but also groundwater, geothermal energy and geo-materials which are main sources for sustainable development of cities.

Underground in urban development plays an important role especially in development of water supply, cleaning and drainage infrastructures and in disposal of industrial waste and solid waste. It is also important in underground urban wastewater disposal. When infiltration capability is sufficient, soil is the most economical recipient for urban flow. It can reduce the need for costly surface drainage measures (Foster et. al., 1998; Foster, 2001).

In different studies for the sustainable development of cities has been mentioned that existing underground use, integration of underground areas into the traditional planning process and these applications will contribute to development of long-term master plans. It is important to understand and scientifically evaluate urban underground resources, to investigate the underground geological structure and properties, to collect and analyze data on engineering conditions for sustainability (Vähäaho, 2016; Tengborg and Sturk, 2016).

Gu et. al. (2016) investigated the relationship of preferred methods in rural wastewater treatment to socioeconomic status. Local governments in rural wastewater treatment plays an important role in selection of technology and application of treatment. The economic support provided by the administrations to the relatively developed and less developed regions may be incompatible. This unconformity may cause applied methods to perform poorly in pollution treatment. The economic status of regions determines technological choices. Preferred wastewater treatment technologies have increased with economic level increasing. As a result of the study has stated that the correct match between technology and socioeconomic conditions must be necessary to properly in order to reduce environmental pollution and to have quality environmental conditions.

Chakraborty et. al. (2017) mentioned that except for landfill of sewage sludge ash, would be an effective alternative approach in the manufacture of construction materials. Countries in light of sustainable developmenta are looking for methods to dispose of sewage sludge especially in order to develop waste management. Sewage sludge is released as a by-product of wastewater treatment (de Oliveira Silva et. al., 2012). In most developed and developing countries have reported to be released annually approximately 70-75 million tons of sewage sludge. Approximately 70-80% of these are used in land application (Asian Development Bank, 2012). The use of improperly treated sewage sludge in land applications may result in organic degradation of soil, the groundwater and leachate contamination.

Krzeminski et. al. (2017) conducted that membrane bioreactor (MBR) technology an investigate to assess energy reduction, contamination control and process performance and to determine overall life cycle (LC) and market potential of MBR. MBR technology have used for good quality treatment of domestic and industrial wastewater and generally for recovery of wastewater. MBR can be expensive especially for places with low population and decentralized sewage system. It has focused on regarding use of MBR, providing economic developments, membrane material production, energy efficiency and low scaling. It has suggested that needs be to developed a holistic approach for LC and environmental impact assessment of MBR. Mutamim et. al. (2012) evaluated MBR performance in high strength industrial wastewater treatment. The majority of industrial wastewater have been successfully treated by MBR. MBR also have performed well in terms of high organic matter removal (Neoh et. al., 2016). Membranes play an important role in separation of solid and liquid (Scott and Hughes, 1996). However, contamination and clogging factors may need to be taken seriously. Because these are main problems affecting MBR performance and wastewater quality. Other factors affecting MBR performance include pH, pressure, temperature, extremely strong chemicals, maintenance of membranes, power of wastewater, etc countable.

Irfan et. al. (2018) noted that uncontrolled or unnoticed disposal of untreated wastewater from industries can severely impair almost all properties of soil. The increase in urbanization has led to construction on these deteriorated lands. The development and design of special improvement materials for soils contaminated with such wastes has an important practical value.

Karim et. al. (2015) conducted a study in urban soils to raise awareness about geochemical basic values and evaluate pollution status of different heavy metals. In the study, metals such as lead (Pb), chromium (Cr), copper (Cu) and zinc (Zn) in soil were determined and the results were compared with estimated base values. Soils in urban environment tend to be affected by many anthropogenic activities. Vehicle emissions, industrial wastes and wastewater sludges have been significant impact on heavy metal contamination of urban soils. This study has shown that urban area soils have an extraordinarily high concentration of Pb. It has been found to have moderate concentrations of Cr and Cu and small concentrations of Zn in urban soils. Urban soils contaminated with heavy metals can pose a risk to the environment and human health.

Ortega et. al. (2008) showed that it is possible to process washing solutions in soils contaminated with organic pollutants and also soil has ability to treat heavy industrial wastewater. In another study, it was removed arsenic using different washing solutions from a soil contaminated with heavy metals (Wang et. al., 2017).

Loy et. al. (2018) investigated the impact of municipal wastewater and brackish groundwater on water retention capacity of clayey-calcareous soils. The results showed that irrigation by municipal wastewater increases existing water retention capacity in upper parts of soil (0-15 cm depth) but decreases water retention capacity in lower parts of soil (15-72 cm depth). Although irrigation by brackish groundwater has no effect on existing water retention capacity in upper parts of the soil, it increased water retention capacity in lower parts. For this reason, irrigation of soil with treated wastewater could increase sustainability of water resources as suitable a irrigation alternative to use of brackish groundwater.

2.5 Performance of Biological Treatments

Kalantary and Kahani (2015) focused on microbiologically induced carbonate precipitate (MICP) to evaluate effect of biological soil improvement methods on sandy soil properties. They formed calcium carbonate precipitates using different microorganisms and catabolic reactions. The results showed that biological sedimentation, time and location can be controlled. It showed that by different culture environments or different bacteria, the risk of liquefaction of soils can be reduced, soil erosion control can be provided, soil pollution can be immobilized and similar soil improvement applications can be potentially used. In addition, unconfined compressive strength (UCS) of poorly graded sandy soil using biological precipitation has increased up to range 100-400 kPa after treatment. Biological soil improvement can enable improvement of physical and mechanical properties of soil by some chemical and biological processes.

Another study that aimed to experimentally analyze effectiveness of MICP use was determined shear strength parameters of two different types soils of low plasticity clay (CI) and high plasticity clay (CH) (Sharma and Ramkrishnan, 2016). Although both clay types offered suitable pore size for microbial movement, it has shown differents in the bond formation (particle-particle interaction) of calcite precipitates. CH soil type has formed a stronger bond than CI soil type. The results have shown that it has a noticeable improvement in UCS of both type of soils with use of MICP. It has been also found that strength increased with an extension of time treatment.

The use of MICP can associated with strength parameter of soil, as well as with bearing capacity of soil, minimized settlements, reduced permeability of soil, reduction of shrinkage-swell behavior and improvement of pore pressure in soil (Wang et. al., 2019). MICP can be counted as economical, sustainable and environmentally friendly technique compared to other soil improvement techniques.

Ivanov and Chu (2008) stated that the mechanical properties of the soil can be improved by applying microbial methods in geotechnical engineering and the porosity and hydraulic conductivity of soil can be reduced by producing pore filling materials by microbial means. Most of the studies in this field in the literature have been resulted as successful (Umar et. al., 2016).

Abo-El-Enein et. al. (2012) studied on sand consolidation and removal of grout cracks as using MICP. In their work, they combined urea+calcium chloride, urea+calcium acetate or urea+calcium nitrate solutions with sand. As a result of this study, the physico-mechanical properties of sand varied according to calcium solution used. Higher compressive strength and lower water absorption can be achieved with proper calcium supply. Carbonates precipitated by microorganisms can be used as attachment material to sand grains and combined with inadequate sands.

Umar et. al. (2016) mentioned that with calcite precipitation caused by microbes, biological soil improvement can be used in order to change properties of soil, such as strength, hardness, compressibility and permeability. However, this reaction may depend on many environmental factors such as temperature and humidity.

Additionally, soil microorganisms and metabolic activities, soil grain distribution, mineralogy, shape, density and texture, reaction and calcite cementation process can affect.

Soil microorganisms can play an important role in formation of fine-grained soils and in changing the behavior of coarse-grained soils (Umar et. al., 2016). Therefore, the use of microorganisms in affecting properties and behavior of soil may be a viable technique. However, it is also recommended to conduct more extensive researchs for MICP in both natural environments and under controlled laboratory conditions (DeJong et. al., 2010).

In another study was placed bacteria and reagents in a 5 m sand column under natural soil conditions to evaluate MICP in soil improvement process (Whiffin et. al., 2007). Reaction parameters in study were monitored under low and high hydraulic pressure. In addition, soil was subjected to a number of mechanical tests. It was concluded that load carrying capacity could be increased without making soil impermeable to liquids. Furthermore, it has been mentioned that precipitation of calcium carbonate by microbial methods gives more successful results under low hydraulic pressure and that MICP can be applied in large scale soil improvement studies. Husssein et. al. (2015) presented that interaction between kaolin clay and an organic compound depends on particle size of kaolin clay.

MICP has been hope in field of geotechnical engineering for soil improvement and groundwater control. The MICP mechanism is definable as 100% efficient when total existing urea is hydrolyzed by bacteria and then produced carbonate and present calcium precipitate as calcium carbonate (Qabany et. al., 2012).

The application of MICP method is often associated with a large reduction in permeability. The porosity of soil decreases with biological blockages occurring in soil structure. As the porosity decreases, permeability of soil decreases and thus it can give very good results in closing leaks in water retention structures (dams etc.) (Umar et. al., 2016; Yıldırım et. al., 2016).

Mtolera and Dongli (2018) aimed to improve nitrate (NO_3), ammonium (NH_4) and TN leaching by microorganisms in coastal soils mixed with 5% -10% gypsum. As a result of study stated that the use of migroorganisms with gypsum has a significant effect in reducing NO_3, NH_4 and TN concentrations in leachate. They also stated that microorganisms support pH and EC regulation of soil. Gypsum is widely used in improving land quality and efficiency (Kim et. al., 2018). It has suggested that the use of microorganisms in combination with gypsum may also provide economic benefits.

2.6 Performance of Membrane Treatments

Önal et. al. (2013) conducted a research on the natural soil properties and geology of solid waste disposal site. Natural soil samples collected from area were performed permeability, water content, specific gravity, atterberg limit tests, sieve analysis, hydrometer analysis and compaction tests. The mineralogical composition and hydraulic conductivity of area was investigated. In their study was concluded that the mineral structure of soil was changed by inorganic pollutants and the area was inefficient in treatment of highly contaminated waste leaks.

Another study aimed to evaluate the shear strength of samples extracted from municipal solid waste (MSW) disposal sites ranging from 2 to 25 years. As a result of this study, the initial highly cohesive loss of waste material by degradation of MSW (soil-like materials) can provide in a gain in terms of shear strength over time. However, it is stated that the content of reinforcement components as a whole must be determined in order to have a good understanding of shear strength behavior. The reinforcing components can correlated well with cohesion intercept increase (Abreu and Vilar, 2017).

Pitarch et. al. (2016) conducted the study to assess potential impact of an urban solid waste treatment plant environment on water quality. In the study, a comprehensive analytical strategy was applied to screen approximately 1500 organic pollutants on surface and groundwater. They have performed the detection and identification of various contaminants of different physico-chemical pollutants and the screening of water samples. As a result of this study has determined that 71% of the most common pollutants in surface and groundwater are pesticides. Transformation products are shown to be most important pollutants that reach groundwater.

Guler et. al. (2018) conducted tests to evaluate hydraulic performance of bentonite-granular soil mixtures that can be used as primer or barrier for waste retention facilities. They added a water-soluble anionic polymer to increase hydraulic capacity to these soil mixtures. Test results have shown that the addition of anionic polymer leads to an increase in internal permeability to a certain measure. On the other hand, even a small polymer concentration has been found to have a significant effect on k_h of bentonite-granular soil mixtures. Due to the increase in viscosity of anionic polymer-added bentonite-granular soil mixtures, inner permeability increased, k_h decreased. As a result of this study, inverse a relationship has been found an between k_h and inner permeability. It has been proposed that polymer-added bentonite-granular soil mixtures can be used effectively as barrier layers in waste storage facilities.

Sivapullaiah et. al. (2003) pointed out that soils displaced with a sufficient amount of bentonite clay are generally used for making primer for water and waste retention facilities. The studies have shown that amount of bentonite varies depending on nature of local soil but a maximum content of 20% bentonite by weight is sufficient. The bentonite content of soil decreases hydraulic conductivity and increases swelling-shrinkage potential of soil. This event may increases loss of strength due to decrease in the cohesion of soil.

Yılmaz et. al. (2008) stated that more research should be carried on geotechnical and electrokinetic properties of CL and CH clays such as stress-strain, swelling, compressibility, cation exchange capacity and adsorption characteristics in order to make reasonable decisions regarding waste landfill usage.

In another study stated that waste storages should be planned as a result of the integrated analysis and long-term isolation of waste storages from the environment should be provided. Waste storages can be areas that transported by air and contain many hazardous substances dissolved in water. Dispersion of these wastes and infiltration into groundwater can be a long-term process that people cannot control. Therefore, the way to protect human health and nature is to ensure complete isolation of waste storages from organic world (Tammemäe and Torn, 2006).

2.7 Effects on Soil Engineering Properties of Inorganic and Organic Liquid

Abedi-Koupai et. al. (2006) found that irrigation systems have a significant effect on infiltration rate, soil bulk density (γ_s) and total porosity. Soil infiltration rate and saturated hydraulic conductivity increased after wastewater land application but decreased by surface irrigation. Samples taken from soil irrigation with wastewater have been observed the smallest optimum water content (ω_{opt}), corresponding to a sharp decrease of soil pore volume and an increase in γ_s (Sou/Dakoure et. al., 2013).

Tang et. al. (2017) evaluated water content and shear strength of marine soils by electro-osmosis experiments. They were considered in factors such as voltage, preload pressure, drainage direction, temperature, processing time in electro-osmosis experiment. As a result of this study, shear strength increased while water content of marine soil decreased with time. Khadge (2005) revealed that siliceous fine-grained sediments in sea soil have a positive relationship with water content and a negative relationship with shear strength. In another study to determine effect of temperature on behavior of saturated and unsaturated sandy clay, it was concluded that maximum strength decreases when temperature increases (Ghembaza et. al., 2015).

Zbik et. al. (2015) conducted microstructure research in an aqueous suspension near LL and PL values in order to better understand water retention behavior of smectite-rich bentonite clays. Smectite ratios in clay suspensions have caused bentonite clay to show different atterberg limit values. In addition, geological age and formations of sample could be as important as mineral combination in atterberg limit values. Smectite-rich clays may exhibit expansion and unusual structure-forming behaviors as a result of wetting due to high dispersal and electrical load. Therefore, it is necessary to evaluate mineral content, clay content and formation as well as solute salt composition and content in preparation of soil samples for geotechnical investigation.

Hajdarwish et. al. (2013) showed that clay mineralogy is related with shear strength parameters. They found that cohesion is related with durability index, specific gravity (G_s), percentage of expandable clay minerals and LL whereas friction angle is related with percentage of expandable clay minerals, absorption, percent of clay 2 μm and LL.

Mortezaei and Karimpour-Fard (2017) investigated the change in hydraulic conductivity of clayey soils exposed to different organic liquids. For this purpose, they investigated on two types of clay with different plasticity that water and methanol as miscible solvents and gasoline and car oil as non-miscible solvents. Properties such as fluid dielectric constant, water content and compaction were determined besides permeability tests.

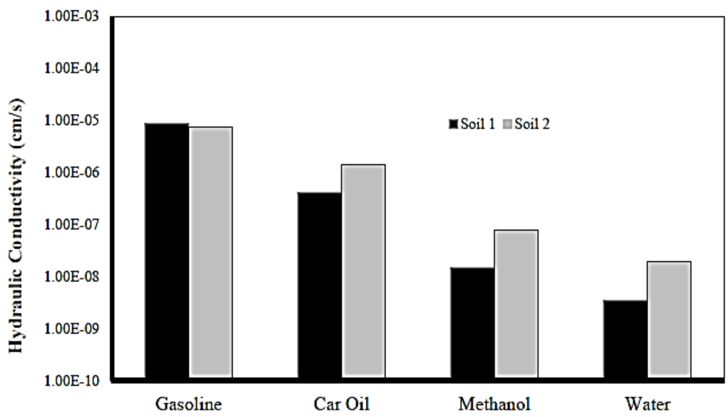


Figure 2.3 Soil permeability at optimum water content for two types of soil for different permeants (Mortezaei and Karimpour-Fard, 2017).

As a result, it has been found that passage of organic liquids through clayey soils initiates a change in soil structure and in this case increases permeability of soil. As clay content of soil increased LL and PI, there was a significant decrease in soil permeability to against mixable liquids such as methanol, while there was a small decrease in permeability to immiscible liquids such as gasoline and car oil. Green et. al. (1981) concluded that organic chemical fluids cause shrinkage of soil structure and cracks. This case caused an increase in soil hydraulic conductivity. When fluids other than water are passed through soil, large increases in permeability was observed due to difference between polarity of water and other fluids.

Estabragh et. al. (2014) investigated on consolidation behavior effect of two clay soils contaminated by two organic fluids (glycerol and ethanol) different concentrations (10, 25 and 40%). Clay soils have consolidated by applying maximum consolidation pressure of 80 kPa which it has allowed bidirectional drainage. As pressure increased, specific volume of soil have decreased. As a result of study, while pre-consolidation pressure was increased for CI, there was no significant change in consolidation pressure for CH. The pre-consolidation pressure have increased as concentration of organic liquid increased. The compression index (C_c) have increased by increasing ethanol concentration. Organic fluids properties have affected consolidation behavior of contaminated soil.

Meegoda and Rajapakse (1993) investigated the effect of short and long term exposure of clays to organic chemicals on hydraulic conductivity (k_h). k_h in short-term permeability test values have shown no significant change in internal permeability of soils. However, long exposure of organic chemicals to soil has caused a changes in soil structure and has shown a significant increase in internal permeability of soil. This state can also cause significant changes in the mechanical properties of soil.

Al-Othman (2009) investigated effect of treated domestic wastewater (TDW) on the physical, chemical and microbial properties of soils. Simulation model used in study was given Figure 2.4. After removing the drainage bed, each column with a diameter of 15 cm and 3.10 m height was added clay-silt mixed soil 526 kg with predominantly sand containing.

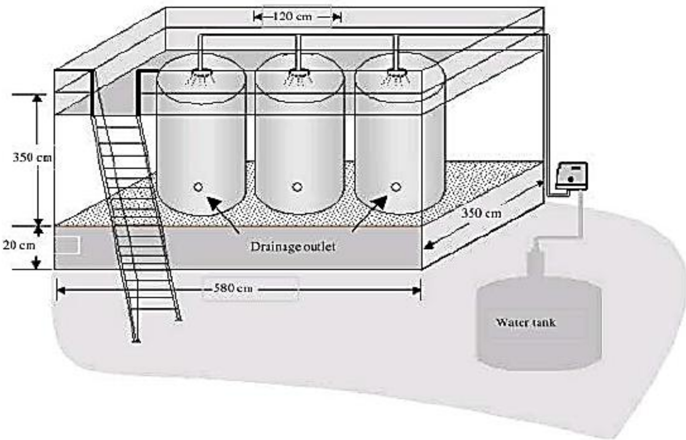


Figure 2.4 Simulation model used in study (Al-Othman, 2009).

Soil samples irrigated with TDW were collected at intervals of 0, 200 and 458 days. As a result, this study have indicated that sandy soils did not affect significantly on physical, chemical and microbial properties counts up to 458 days of irrigation with TDW. The effect of TDW was less pronounced because of the predominantly sandy of soils (80.0, 88.4 and 90.9% respectively) and low cation exchange capacities and low water retention capacities.

Duan et. al. (2010) evaluated the effects of wastewater land application system on soil chemical properties. Soil samples were taken from different depths up to 91 cm from surface of research site of 972 m^2. The PH, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen (TKN), sodium (Na^+) and sodium absorption rate (SAR) were analyzed for soil samples with and without wastewater application. All analysis results were evaluated by using statistical software package SigmaStat. Consequently, Nitrate-nitrogen has shown no differences throughout soil profile tested (down to a depth of 90 cm). pH values have shown no statistically significant difference ($p=0.085$). Salt and SAR tested have noticed no significant differences ($p<0.05$) in concentrations found between samples collected at the beginning of tests and its collected after wastewater application. TKN and ammonia-nitrogen in top layer of soil have contained significantly ($p<0.05$) higher concentrations than in lower layers of soil profile. The research results have shown that there is no negative change in soil chemical properties. Also, it has stated treated wastewater can be designed and operated in such a way that land application does not have a negative impact on environment.

Dempster et. al. (2012) used clay and biochar to reduce the amount of nitrogen (N) leaking from coarse soils. As result, they have stated that both biochar and clay have significantly decreased ammonium (NH_4^+) leaching by about 20% and nitrate (NO_3) leaching by about 25%.

Tabatabaei et. al. (2017) showed that there was no significant effect of wastewater on soil pH. The wastewater applied to a sandy soil caused an increase in soil EC in top layer but a decrease in lower layer.

Matichenkov et. al. (2017) stated that phosphorus (P) level affects low adsorption capacity of sandy soils. Silicon (Si)-rich soils have potential to improve low absorption capacity of sandy soils for reduction of P leaching from soils. Increasing soil adsorption capacity have can affected soils properties chemical and physical.

In a study examining the effects of industrial wastewater on soil properties was stated that of change degree of soil properties depend on the amount of fine material in soil, that is, clay type and minerals. The reason for the change of properties of contaminant and clay could be depend on base exchange capacity, dispersed double layer structure, dielectric constant and structure of contaminant. When the contaminant comes into contact with clay, it changed weight of clay by affecting dielectric constant. An increase in dielectric constant reduces shear strength between parts and increases double layer thickness and increases LL. The swelling properties of clayey soil have also affected by changeable ions. Contaminated soil has indicated that the increase in

Na^+ content may cause more swelling. The void ratio in soil has decreased with an increase in contaminating load (Shah and Shroff, 1998).

Ijimdiya (2011) investigated the effect of oil pollution on particle size distribution and plasticity properties of lateritic soil. The soil has been artificially contaminated with a maximum 6% oil content by weight of dry soil. The results have shown that plasticity modulus, plasticity product, shrinkage modulus and grading modulus decreased with increasing amounts of oil content. The PI have decreased from 16% to 8.5% when contaminated with 6% oil content. Daka (2015) stated that oil pollution causes a decrease in fine aggregate in soil. Oil contaminated soils have shown on decreased of γ_{kmax} and ω_{opt}. The hydraulic conductivity of contamined soils have decreased as oil contamination increased.

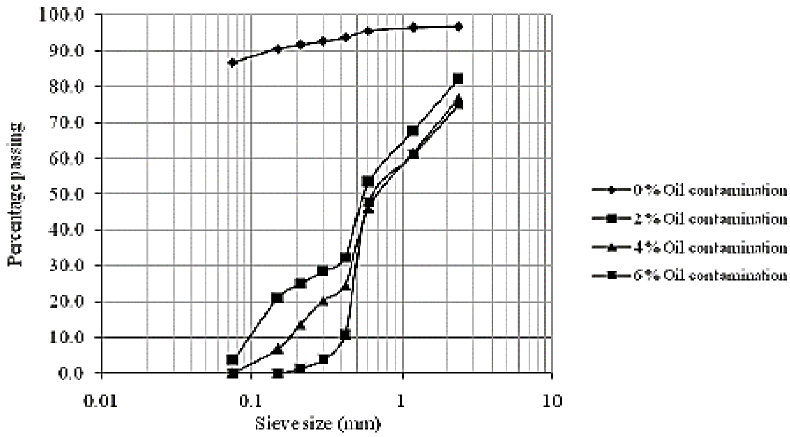


Figure 2.5 Aggregate size distribution of uncontaminated and contaminated lateritic soil (Ijimdiya, 2011).

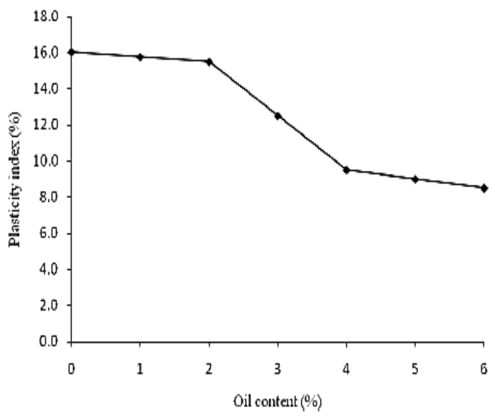


Figure 2.6 Variation of plasticity index with oil content (Ijimdiya, 2011).

A another study, samples was prepared by mixing sand with oil in amount of 6%. This samples have been made compaction and permeability, CBR, triaxial tests, consolidation tests and direct shear tests. According to test results, compaction properties and CBR values of sand have improved by presence of up to 4% oil. However, these values have been sharply decreased with 6% oil. Oil contamination have been decreased permeability and strength. Oil contamination have been increased compressibility. This result has been proven with increased C_c in consolidation test (Al-Sanad et. al., 1995).

Talukdar (2014) investigated changes in properties of crude oil contaminated clayey sands. LL, PL, PI, swell indexs and pH value has increased linearly whereas UCS and EC has decreased linearly with increase in percentage of crude oil contamination.

Pineda et. al. (2013) investigated effects of pore fluid salinity on the shear strength of a soft clay. Direct shear tests has carried out on natural samples using pore fluids with different salt concentrations. As a result of this study, they emphasized that pore water salinity has a significant effect on both compressibility and shear strength of clay. Strength parameters have decreased with decreasing of salt concentration. Cyrus et. al. (2010) stated that soil compressibility decreased with salt concentration. In addition, it has stated that LL and PI values decreased due to addition of salt to clay soils.

Irfan et. al. (2018) investigated effect of industrial wastewater (acidic) and tannery (basic) water, CH and CL. As a result of this study, LL and PI values of contaminated soils have shown increase. Specific gravity of soils contaminated with wastewater decreased by 12% to 15% due to lower specific gravity of industrial wastewater. Contamination has been to cause an increase in compression index of soil about 30% to 40%. UCS have decreased rapidly ratio 60% with acid and basic contamination. It suggests that in future studies could be carried out determine impact of wastewater and other pollutants on CBR of cohesive soils.

Karkush and Resol (2015) investigated the effect of industrial wastewater on physical and chemical properties of sandy soil. They damped with pollutants for 30 days by distilling at a rate of 10, 20, 40, 100% the soil samples in plastic container. As a result of this study, LL of contaminated soil samples increased compared to uncontaminated soil. The γ_{kmax} of contaminated soil samples decreased as percentage of contaminants increased. There was a small decrease in specific weights of contaminated soil samples. The increase in contamination percentage caused a decrease in permeability of contaminated soil samples.

Ramya et. al. (2018) exposed black soil to calcium chloride solution in various concentrations. The LL, PL and PI values of soil treated with calcium chloride has observed to decrease. It has observed that at higher concentrations γ_{kmax} increased but there was no significant change in ω_{opt}. Treated soil has been made to UCS for 1 day, 7, 14 and 28 days. Strength of soil has increased with increasing in concentration and curing period. Permeability have increased with increase in concentrations of treated soil. Grain distribution analyses by adding calcium chloride solution have shown decrease in percentage of clay from 64% to 47% and increase in percentage of silt from 24% to 41%.

Ratnaweera and Meegoda (2006) showed that a decrease in shear strength and stress-strain behavior of soils which with UCS tests made on clayey silt soils contaminated in different rates chemicals. These decrease have been stated to will may affect in dielectric constant and pore fluid viscosity.

Yılmaz et. al. (2008) conducted hydraulic conductivity tests on CL and CH compacted with inorganic salt solutions. These tests have been experimentally carried out different concentrations five inorganic salt solutions which sodium chloride (NaCl), ammonium chloride (NH_4Cl), potassium chloride (KCl), calcium dichloride ($CaCl_2$) and iron trichloride ($FeCl_3$). EC values and pH values of clays with inorganic salt solutions have chanced and also effect of inorganic salt solutions on CL have shown differents from that on CH. While hydraulic conductivity have increased for CH clay when salt concentrations increased, hydraulic conductivity decreased for CL clay when salt concentrations increased.

Hasan et. al. (2014) conducted a research to examine the effects of using treated wastewater (TWW) on physical and chemical properties of soil. They used 5 different water; 100% potable water (PW), 100% TWW, 25% PW + 75% TWW, 50% PW + 50% TWW and 75% PW + 25% TWW. PH, EC, organic matter content, total stability and pore size distribution were determined before and after irrigation of soil. In addition, some element contents of soil such as K, Mg, Na and Ca were determined.

In general, while aggregate stability have changed at experiments, pore size have not changed significantly. The Na in soil has accumulated more than Ca. Increasing Na content in soil has increased dispersion of soil and decreased water retention of soil. Soil salinity for TWW irrigation operations has found to have the highest concentrations of Na, Ca, Mg and K respectively.

Lesmes and Friedman (2005) stated that relationship between soils EC value and water content (or k_h) is important in engineering. Also, determination electrical properties of a soil can be used to qualitative evaluate porosity and pore fluid properties. It can be possible to estimate areas of soil that need improvement, spatial distribution of existing clay and some soil chemical properties by EC (Sanches et. al., 2018).

Stern and Shackelford (1998) stated that will may decreases hydraulic conductivity of sand-bentonite mixture by adding calcium chloride ($CaCl_2$) and that the concentration of solution and percentage of clay in mixture are important.

Alhassan and Fagge (2013) investigated effects on the geotechnical properties sand, clay and laterite soils of contaminants like crude oil, fuel oil and gas oil. Contaminants have been mixed to ratio 2%, 4% and 6% by weight of soil type. As a result of this study, CBR values have generally decreased with oil contaminations. Consolidation settlement of contaminated clays soil has generally decreased for all contaminants. All contaminated has increased in shear strength values with ratio 2-6%.

Another in study with triaxial compression and oedometer tests were examined how that freezing-thawing (FT) and drying-wetting (DW) effect hydraulic conductivity of CH. Tests were carried out by adding tap water, sodium carbonate or dimethyl sulfoxide solution to clay. As a result of this study, they stated that DW and FT effects could cause strong crack structures in CH. These cracks have expected to cause big increases in hydraulic conductivity. If sodium carbonate solution add, these increases significantly have reduced in FT and DW samples (Graham et. al., 2001).

Berry and Burton (1997) showed that petroleum hydrocarbons are rapidly decreasing in dense clayey soils. It is stated that strong combinations of low k_h and hydrocarbons with organic matter and clays could reduce groundwater pollution threat.

Sivapullaiah (2009) investigated that effects on soil geotechnical behaviour of soil pollution. Soils are able to change swelling and compressive behavior when interact with different pore fluids. The amount of swelling occurring in soil usually depends on the type of mineral in soil and concentration of acid solutions. Unexpected pores may occur due to contamination in swollen and non-swollen soils.

Acids are commonly present in surface sediments and can easily interact with soil. For example, acid sulphate contamination of soil causes swelling that increases over time as depends on soil mineralogy (Pons, 1973). Stephenson et. al. (1989) reported that can move upwards of soils due to presence of sulphuric acid. The reason that foundation soils are exposed to excessive acid pollutants could leads to an increase in the number of failure of structures. The compressibility of soil is also marginally increased by influence of acids (Chavali and Ponnapureddy, 2018). New compounds can formed by reaction of clay and alkaline solutions. These compounds can affect soil adsorption and specific surface area. Specific gravity of contaminated clays soil have generally reduced (Sivapullaiah and Manju, 2005).

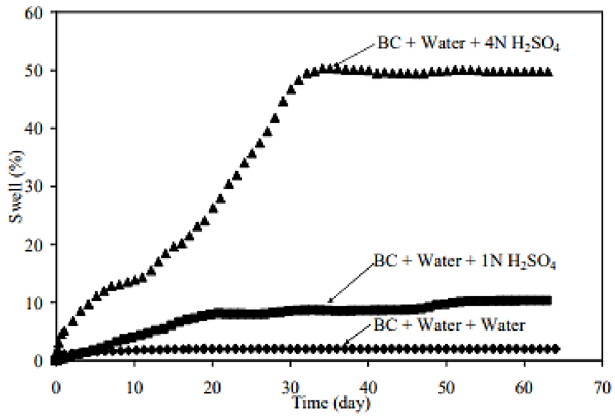


Figure 2.7 Swell behaviour of expansive soil with sulphuric acid solutions, BC: Bentonite clay (Sivapullaiah, 2009).

Stawinski et. al. (1990) investigated the effect of calcium (Ca^{2+}) and sodium (Na^{+}) concentrations on microscopic structure of bentonite and kaolin clays. Clays were clustered in distilled water and in various electrolyte concentrations. Average grain radius of clays were determined and sedimentation rates were examined. Because sedimentation rate is proportional to density of scattered phase and square of grain radius, if clustering of grains increases, sedimentation rate increases. Consequently, the increase in suspension concentration has led to increased grain radius. The increase in salt concentration has caused inter-grain defloculation and hence average grain diameter reaching minimum values.

Singh et. al. (2008) evaluated the settlement characteristics of clayey soils contaminated with petroleum hydrocarbons. Index properties and consolidation tests of soil samples were determined before and after contamination. The four most common petroleum hydrocarbons were combined with CL and CH. As a result of this study, it has observed that the coefficient of consolidation (C_v) decreases with contamination for fine-grained soils. A decrease in value of C_v showed that consolidation could take place at slower. Consolidation settlement for soils contaminated increased because of increased in value of compression index.

Response to against contaminants of soil depends on particle size to interact with contaminants, binding properties between particles, ion exchange capacity, type of soil, degree of saturation, stress history, nature of pore fluid and contaminants (Singh et. al., 2008). Properties of soil due to chemical/organic contaminants can chanced significantly (Mosavat and Nalbantoglu, 2011; Matteo et. al., 2011). Sridharan et. al. (1981) revealed that soil contained high phosphate of contain in acidic environment which in turn could be linked up with phosphoric acid as source of contamination. This have been resulted swelling and different movement of soil.

Thakur et. al. (2005) carried out experiments in order to determine parameters effecting soil-water characteristic curves of fine grained soils. The results have revealed that dry density (γ_k) has negligible influence on soil suction and parameters effecting soil-water characteristic curves.

Mosavat and Nalbantoglu (2011) investigated effects on sedimentation time, plasticity and shear strength of clayey soils which ethylene glycol solution of prepared with different percentages (0, 20, 40 and 60%). The results showed that the shear strength of the contaminated soils decreases with increasing percentage of ethylene glycol. As ethylene glycol content of clay soil increases, plasticity has decreased. It also has been caused changes in sedimentation time of particles in hydrometer test of the clay soils.

Jedari and Hamidi (2015) investigated LL, PI and compaction properties of clayey soils like bentinite and kaolinite contaminated with organic liquids. The results have shown that been increases of LL and PI of soil about 30% and 10% respectively. Also, it has lead to decreased of ω_{opt}.

Nguetnkam et. al. (2011) treated with sulphuric acid solutions of Cameroonian clays. In this study, acid activation of cameroonian clays have displayed a decrease in cation exchange capacity with increasing sulphuric acid concentrations. There has been a significant increase in specific surface area of natural cameroon clays with the effect of acid.

Matteo et. al. (2011) investiged consolidation of kaolinitic clay contaminated by ethanol-gasoline mixed. The results obtained in this study have indicated that a minimum of compression index (C_c) for kaolinite clay could reached when water was used as pore fluid.

In another study, hydraulic properties and microbial soil contamination have been determined before and after wastewater application. Wastewater application have resulted in increased microbial contamination on soil surface. This research has indicated that effects wastewater on soil properties increase of soil bulk density, decrease of soil porosity and as a result of study, the decrease of soil hydraulic conductivity and permeability (Aiello et. al., 2007).

Deneele et. al. (2010) expressed that lime-treated soils will may be an option for filling deep nuclear waste repositories. In this study have investigated that effect of alkaline solution (pH>12) to lime-treated compacted clayey soil sample. It has been assessed soil pieces by scanning electron microscopy (SEM) and energy dispersive X-ray. Highly alkaline solution have been induced changes in porosity, swelling and sorption capacities. They have shown an increase in porosity and permeability of compacted bentonite. Alkaline solution has not produced a significant modification of shear strength behavior of lime-treated clay soils.

Tahtouh et. al. (2019) evaluated the impact of irrigation with treated wastewater (TWW) and brackish groundwater (BGW) on the chemical and mineralogical properties of a calcareous clayey soil. This study have shown that TWW has a better quality (pH, salinity, chloride, sodium, and sulfate) than BGW. Although the results obtained from analyses have shown that values such as SAR and EC increased marginally compared to control soil, The chemistry and mineralogy of soil have been shown no significant changes resulting from use of TWW and BGW.

Stark et. al. (2014) investigated that compressibility of soil with unsaturated seepage analyses. In their study, they presented informations on temporary leakage, soil compressibility and selection of hydraulic conductivity values. They stated the importance of m_v value in deriving temporary leakage flow and that this value is a function of both soil structure and water compressibility.

Maharaj and Paige-Green (2013) worked to determine the dispersivity of soil by adding sodium hexametaphosphate, sodium carbonate, sodium silicate and sodium oxalate solution to 1 L of water. Different soil samples have been wait approximately 16 hours for dispersion. In their work, they have shown that clay fraction has significant differences. With the addition of solution have been cases when soil has not completely dispersed or all soil clusters have not completely decomposed.

Prakash and Arumairaj (2015) attempted to determine the effects of acid and base contamination on geotechnical properties of clay. They used CH soil for the study. Clay sample have been added contaminants that hydrochloric acid (HCL), nitrous acid (HNO_3) and sulphuric acid (H_2SO_4) as acid and that sodium hydroxide (NaOH), potassium hydroxide (KOH) and calcium hydroxide as base. The acid and base contaminants have added at an raises of 5% by weight of dry soil samples and maximum in the ratio of 30%. As acid contamination increased, while LL, PI, G_s, ω_{opt} and γ_{kmax} and shear strength of clayey sample have decreased, swelling values have increased. As base contamination increased, while LL, swelling values, ω_{opt} and γ_{kmax} of clayey sample have decreased, PI, G_s and shear strength have increased.

Umesta et. al. (2012) stated that acid contamination of the soil negatively affects the geotechnical properties. They investigated in study that the atterberg limits, compaction properties and unconfined compressive strength of acid contaminated soils. According to the Atterberg limit test results, LL and PI decreased, PL increased in general. A decrease in dry density and strength was observed as the contaminant increased.

Kermani and Ebadi (2012) stated that petrochemical activities, oil spills, pipeline and reservoir leakage etc of contaminants in terms of groundwater pollution and change of geotechnical properties of contaminated soil cause concerns. For this reason, some laboratory tests were carried out on both uncontaminated and contaminated fine-grained soils containing crude oil. As content of the oil contaminant increased, γ_{kmax}, PL, small amount of LL, internal friction angle (φ) and compressibility of soil increased, ω_{opt} and PI decreased. It can be stated that contaminated soils can be compacted more easily in intense configurations.

Nazir (2011) investigated the effect of motor oil contamination on consolidated clay. In experimental study have revealed that UCS is decreased by approximate 38% as compared to uncontaminated soil. Significant changes have been seen in microstructure of clay. There have been significant declines in both liquid and plastic limits. The permeability coefficient has increased approximately 3 times value of control sample value in proportion with contamination time. Compaction and swelling index values have increased as time of contamination increased. Contamination has been shown a small effect on over-consolidation rate.

Resmi et. al. (2011) presented changes occurring in index and engineering properties of two clay soil types contaminated with different lead concentrations. They have stated that when soils were contaminated with high lead concentrations, various engineering properties changed. As amount of lead (Pb) adsorbed by soil increased, LL, PL, swelling properties and bearing strength decreased and a significant increased in consolidation and permeability coefficient have occurred.

2.8 Soil Clogging

The formation, cause and development of clogging in soil is a dynamic process that can be explained by physical, biological and chemical factors. Biological clogging is related to formation of bacterial mat (impermeable biofilms) (Vandevivere and Baveye, 1992). In fact, the biomate acts as a filter in removal of pathogens, leaching and trapping of organic matter. But, if the vadose zone of the soil does not have oxygen needed to break up biomate, anaerobic conditions occur. Thus, accumulated waste materials and metabolically formed by-products causes soil clogging and loss of infiltration capacity (U.S. EPA, 2002). Rodgers et. al. (2004) showed that the main mechanism responsible for clogging in sand filters was biofilm development.

Biological clogging usually develops as a result of physical clogging. Physical clogging can be directly related to pore size of natural soil. Physical clogging occurs when suspended partucule size in wastewater is larger than soil pores (Jnad, 2000). Physical clogging on the soil surface may be one of the main reasons for infiltration reduction (Rice, 1974).

Chemical clogging can be said to occur from interaction between water, wastewater and dissolved salts in soil. Chemical clogging occurs when concentration of Na in water is high, through dispersal and swelling of clay particles (Jnad, 2000). The ratio of Na in soil structure water, irrigation water or wastewater can be estimated using sodium adsorption ratio (SAR) depending on Ca and Mg ions concentrations.

The Na in water that interacts with soil makes ion exchange with cations in soil structure. Ion exchange of Ca and Mg cations causes degradation of soil structure, breaking into smaller pieces and decreasing porosity. This case decreases filtration of soil and prevents soil from getting air (Ak and Top, 2018).

The SAR value can usually evaluated in associated with salinity i.e. EC. In this respect, SAR and EC values can be estimated relatively that potential filtration problem of water can cause in soil.

Zhou et. al. (2018) stated that as concentration of Ca^{2+} and Mg^{2+} in recycled water increases, accumulation of clogging substances in soil accelerated (Quartz, silicate, carbonate and salt mineral components).

Suarez and Gonzalez-Rubio (2017) investigated the effects of dissolved organic carbon (DOC) in treated municipal wastewater used for irrigation purposes on soil seepage in relation to SAR and pH. In their study, they concluded that SAR, DOC and pH values in wastewater can lower the rate of soil infiltration and have a harmful effect on physical properties of soil. In case of SAR increases from 4 to 7 and pH increases from 7 to 8 infiltration of soil and aggregate stability decreased and dispersibility increased. They has suggested that PH should be decreased to below 8 in and SAR to below 4 in regard to use of wastewater for irrigation purposes.

Patterson (1997) reported that wastewater with SAR>3 can significantly reduce the hydraulic conductivity of soil. In their studies, as SAR increased, they have clearly demonstrated loss of saturated hydraulic conductivity (k_{sat}). The results are statistically significant as shown in Figure 2.8.

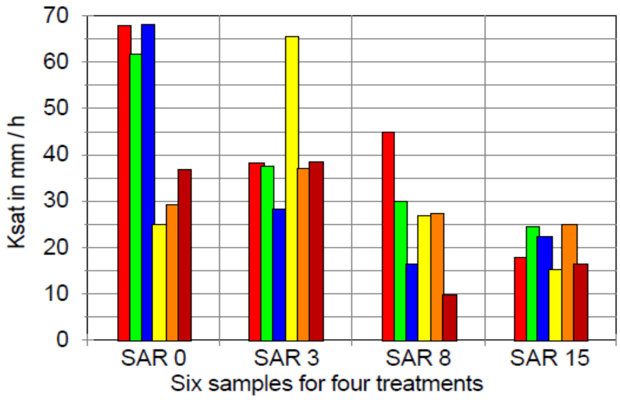


Figure 2.8 Effect of domestic septic tank wastewater on surface chocolate soils (Patterson, 1997).

Figure 2.8 has shown that systems need to be operated with water with lower SAR value in order to maintain long-term hydraulic conductivity of soil disposal sites and to ensure final treatment efficiency in wastewater.

Jnad (2000) investigated change in soil hydraulic conductivity in drip distribution system drainage. He was filled its interior with soil containing 44% sand, 40% silt, and 16% clay by building a tank with a depth of 110 cm and measuring 80 cm x 80 cm. Domestic septic tank wastewater was applied to tank. The chemical properties depending on wastewater application were analyzed k_{sat}, water retention and pore size distribution of collected soil samples. In general, the higher water retention of soil by application of wastewater has resulted in a decrease in volume of pores and a decrease in value of k_{sat}. An increase in Na concentration associated with a decrease in Ca concentration has shown to increase the risk of swelling and dispersion of clay particle. It has stated that the decrease in k_{sat} may also be due to microbial activity and Na induced clay dispersion.

2.9 Soil Filter

Keesstra et. al. (2012) investigated soil as a filter for groundwater quality. They stated that the filtering function of soil is an important ecosystem service and this filtering efficiency depends on concentration of contaminants in soil and hydrological processes. They stated that many organic and inorganic compounds obtained from agricultural, municipal or industrial by-products can be filtered, buffered and decomposed by soil biota with clay minerals and organic matter. However, they suggested that the effect of different climatic conditions on the filtration potential of the soil and the relationship of filtration with time should be determined.

The physical, chemical and biological composition of wastewater can exhibit variability greatly. Clays can more affected by water than other soil classes in terms of mineralogical structure. For example, clays are traditionally known as an impermeable material. But, since clays have high ionic interaction power, contact with different chemicals can change its structure and behavior. As a result of this change is stated that there may be a significant increase in permeability of clay (Guler et. al., 2018).

Treese et. al. (2012) compared disturbed soil and undisturbed soil samples used in infiltration. This study has provided opportunity to evaluate whether the area is required for disturbed and undisturbed soils to provide good a infiltration in soils. Consequently, disturbed soil has retained N and P emission at 0.4 and 0.8 m infiltration compared to intact soil. The release of nitrogen in intact soil has took longer time. It has stated that the deterioration of soil structure accelerates time of N release.

Bester and Schafer (2009) investigated the role of active soil filters in removing micro pollutants from storm and wastewater. They created an active soil filter system with a scale of 0.12 m^3 in order to eliminate some organic micro pollutants. In their study, they showed how stable soil filters are eliminating organic compounds from water. As a result of this study, it has been mentioned that soil filters can be used in storm water treatment, sewage overflow and wastewater treatment and these systems are a more cost effective treatment option in places without central sewage or in small applications. It is stated that the estimated operating times of soil filter systems can be approximately 100 years for a stacking height of 2 m per year.

Duborsk et. al. (2019) evaluated the absorption behavior of two inorganic iodine species which are most naturally present in various soil types. In experimental study, they observed that the absorption behavior of soil was quite slow after 10 days. Iodine can reduces by double-valued iron (Fe) found in clay minerals, thus can create forms that can be easily attached to soil particles. There can a strong correlation between the amount of clay in soil and absorption of iodide (Hu et. al., 2009). Furthermore, a statistically significant relationship has found between absorption capacity of soil, TOC, humic substances and fulvic acids content. Although iodide absorption efficiency is more dominant in mineral soils with low OC content, mineral soils with high OC content may be more suitable for iodide absorption. Because OC, clay content, PH, Fe, aluminum and manganesoxide abundance are the most important soil properties affecting iodine absorption. In another study, the lowest iodine absorption value has found after the chemical removal of organic mineral complexes from soil (Li et. al., 2017).

2.10 Soil Column Studies

Martins et. al. (2017) simulated the infiltration basin conditions with a series of soil-columns, using soil which is a waste environment, to improve wastewater quality before delivery of wastewater directly to the aquifer. Soil-columns have been filled with both natural soil (81.91% sand, 15.95% silt and 2.14% clay) and soil mixture (40% natural soil, 40% artificial sand and 20% organic matter). Different time lengths, thickness and injection methods has been tested.

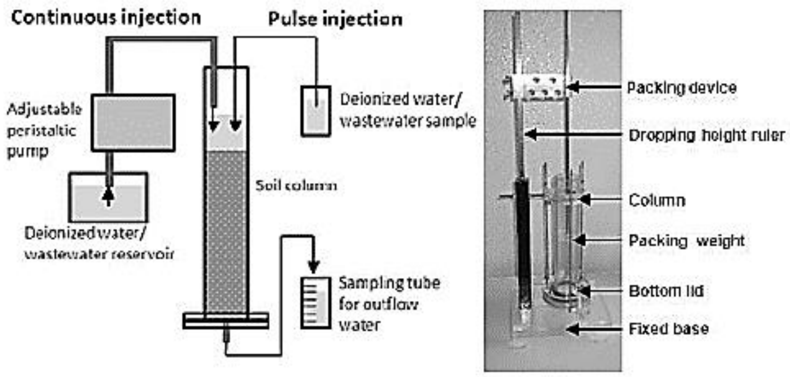


Figure 2.9 Soil-column experiments apparatus (Martins et. al., 2017).

As a result of this study, soil infiltration systems have been stated to have minimum negative environmental impact. The increase in percentage of organic matter in soil has contributed to the increase of biological activity or biodegradation processes. Maximum attenuation efficiency in removal of contaminants in wastewater have been provided under oxic/anoxic conditions. The presence of high pH depending on soil type has facilitated retention of some heavy metals.

Mojid et. al. (2019) investigated the effects of municipal wastewater on soil properties with soil column experiment in laboratory. In their study, they aimed to determine the effects of municipal wastewater on soil health and to develop functional relationships between hydrophysico-chemical properties of soils irrigated with wastewater. Accordingly, the 4 most common natural soil samples in Bangladesh were collected from agricultural areas. 4 soil columns were prepared by placing soils in PVC columns of 15 cm diameter and 34 cm height. The amount of organic carbon has increased significantly in soil columns irrigated with wastewater with a typical domestic wastewater quality. As OC increased, density, porosity and k_{sat} of soil has decreased. Negative correlation between percentage clay content of soils and porosity distribution index after wastewater treatment has become significant ($p < 0.05$).

Wen-zhi et. al. (2013) investigated the effects of different fertilization applications on nitrogen (N) in soil, initial salinity rate and salinity transport in soil. Plexi-glass columns (18.2 cm in diameter and 100 cm long) was filled with optimum saturated sand. Irrigation water solutions of different contents were applied equally and slowly in plexi-glass columns. This study was concluded that high soil salt content may increase infiltration rate, water content decreases as soil depth increases, amount of irrigation water significantly affects transport of soil salinity and its a strong correlation between chloride ion and nitrate nitrogen content in soil profile.

Murugaiyan and Saravanane (2009) investigated the effect of pharmaceutical wastewater on physico-chemical behavior and geotechnical properties of clayey and silty soils. It was designed soil-column experiment setup consists of 90 mm outer diameters and 80 mm height 5 PVC pipes batteries. Pharmaceutical wastewater has shown more persistence of chloride and sulfate in soil mass due to artificial contamination in bentonite clay. COD in kaolinite clay has completely retained at the end of 16^{th} hour. The effect of wastewater on all soils has reduced shear strength of soils by about 20%. In the study, it has stated that the properties of soil will change in interaction of organic or inorganic wastewater with a soil content of at least 35% clay. In a similar study, the determination of 14 different drugs which are known to be able to remove a small amount during wastewater treatment of soil has explained by analytical method. In the study, all the pharmaceutically active compounds studied have found to accumulate in soil at low or high concentrations (Montemurro et. al., 2019).

Oluremi et. al. (2012) investigated the effect of cassava wastewater on geotechnical properties of lateritic soil. Lateritic soil material was placed in a container approximately 0.90 m high and 0.50 m in diameter compacted in 5 layers. Cassava wastewater was poured into soil at 7 day intervals over a 28 day period. Particle size distribution analysis, atterberg limits, compaction, CBR tests were performed on contaminated and non-contaminated soil samples. Test results were showed that cassava wastewater affects geotechnical properties of soil.

Gross (1984) built sand filter columns from 4 inch PVC pipe for septic tank virus removal by sand filter. In this study, TOC, cell culture and concentration, virus, etc carried out analyses. It was concluded that the capacity of sand columns to absorb some viruses is independent of hydraulic loading and that most viruses are retain within first few centimeters of biologically active sand. In another study carried out on four different sand soils using 100 cm long columns, the effectiveness of removing virus from wastewater showed large differences among soil types with different gradation and appeared to be largely related with hydraulic flow rates (Wang et. al., 1981).

Qin et. al. (2014) developed 3 types of SWIS to investigate the removal of organic contaminants from dispersed rural sewage water.

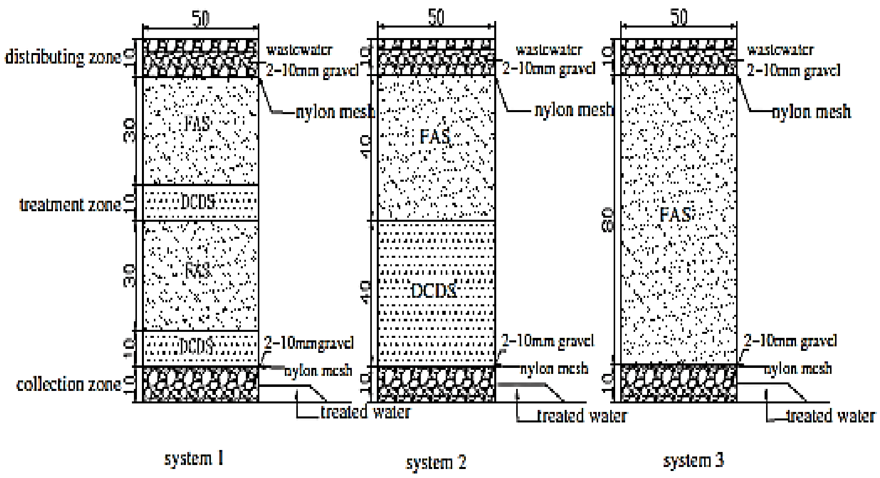


Figure 2.10 Schematic diagram of SWIS (Qin et. al., 2014).

SWIS's have composed of fly ash (5%) and soil (95%) and is called FAS; the other has composed of decomposed cow dung (5%) and soil (95%) and is called DCDS. SWIS was operated with hydraulic loads of 6.5 cm/d, 13 cm/d and 20 cm/d respectively in 3 month periods. All samples have been analysed for chemical oxygen demand (COD), total phosphorus (TP), ammonia nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), total nitrogen (TN) as of 2 weeks. System 2-SWIS has been most favourable for rural sewage treatment at end of 3 months. Hydraulic loads have had little effect on separation efficiency of COD and NH_4^+-N. TN removing efficiency has increased with increasing DCDS height. TN removal efficiency has found at a rate of 25% in System-3 and 72% in System-2 and 31% in System-1.

Zheng et. al. (2016) simulated SWIS as a soil column consisting of a 30 cm diameter and 100 cm high PVC pipe. In the study, SWIS's were shown to have a high rate of TN and NH_4^+-N removal. It has been suggested that optimum hydraulic load and pollutant concentration should be determined in order to prevent groundwater pollution.

Wang et. al. (2014) investigated the sewage water treatment effects of natural soils. They used natural soil that received from a point deeper than half a meter and water that received from the wastewater treatment plant. Wastewater was added which soil samples in plexiglass pipes with a diameter of 10 cm and a height of 90 cm and it provided water effluent under pipe. As a result of this study was mentioned that wastewater treatment is related with soil depth and soil grain diameter and that natural soil is efficient and safe in wastewater treatment.

Kadam et. al. (2009) reported the treatment of urban wastewater in laterite soil-based constructed soil filter (CSF) system. Composite soil samples were taken from a depth of 120-150 cm and 30-50 cm subjected to studies many physicochemical. As a result of this study, CSF with laterite soil environment provided positive contribution to removal of COD, BOD, ammonia-NH_3, nitrite-NO_2, SS. Also, they indicated reducing turbidity in wastewater, removing color and odor, chemical pollutants and pathogen removals can be achieved with low energy.

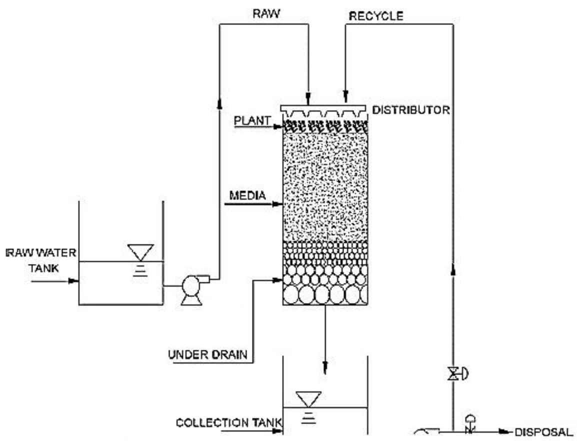


Figure 2.11 Schematic of CSF process (Kadam et. al., 2009).

Lewis and Sjöstrom (2010) examined the literature on formation both saturated and unsaturated soil columns. The studies have been performed that indicate that unsaturated soil columns in small-scale experiments can be a good practice to ensure the heterogeneous of soil and it can be a better practice as long as dry soil is allowed to saturate in large-scale experiments. Flow in saturated soil can be explained by ideal flow models and can be preferred to minimize lateral flow effects. Nevertheless, it has been stated that although soil column has been used for many years, it has not reached any standardization and different techniques and approaches will contribute to results obtained.

2.11 Literature Summary

It is possible to reach all kinds of organic and inorganic substances are caused by people's activities to soil. In this respect, it is important to estimate transformation soil, potential for groundwater transfer and the properties of these organic and inorganic substance for the determination of environmental impacts.

In recent century, studies of onsite wastewater treatment methods and examining of the interaction of wastewater and other contaminants with soil are common almost all over the world.

The use of soil which is a waste environment and utilization filtration properties of soil in order to remove contaminant wastewater is a fact of nature.

For this reason, successful results are obtained with simulated soil-columns for experimental studies. Current studies evaluate wastewater treatment systems and treatment;

1. To evaluate efficiency of existing systems and to describe water reuse options include membrane systems, biological and electro-osmotic improvement methods, etc.
2. To enhance infiltration basins,
3. To increase water availability and quality,
4. To identify or minimize contamination of septic tank systems near groundwater or surface water,
5. To reuse low quality water into water cycle,
6. To find solutions to water scarcity problems especially in arid and semi-arid regions,
7. To develop relatively inexpensive and simple treatment methods with minimum environmental problems,
8. To investigate the effect of soils in wastewater treatment and to develop optimum efficiency conditions,
9. To determine soil-contaminant interactions according to concentration of inorganic and organic contaminants.

In this context, soil-column experiments are not suitable leakage behavior in a field conditions. On the other hand, they can be used to estimate the leakage rate, analyses of organic and inorganic substances, leakage behavior physical, chemical and mineralogical properties of soil.

This study can contribute to determine referance values for leakage water quality thanks to using soil coloums. Minimum discharge criteria of treatment can be changed by managent, legislation and regulation of countries. In addition, some researches explain effects organic or inorganic contaminants different from drinkable water on physical, chemical and mineralogical properties of soil. Furthermore, researches show that microorganisms, bacteria, various pathogens and their metabolic activities play an important role in influencing properties and behavior of a soil. However, it can be said that these studies are insufficient to estimate the effect of wastewater on engineering properties of natural soils. This study will be a feasibility study for future infrastructure and superstructure studies, especially in areas where onsite wastewater treatment system is used. For this purpose, this study will make an important contribution to literature and shed light on future studies.

This study is also important for analysis and comparison of isolation techniques and available data in order to obtain an advanced approach.

CHAPTER 3

MATERIALS AND METHODS

3.1 General

This chapter presents informations on source of materials (soil and wastewater) and research methodology. This chapter contains information about research model and how to conduct research. In addition, the method of material collection and techniques by which materials are analyzed are clearly defined.

3.2 Materials for the research

3.2.1 Soils

In this study, natural soils which obtained from 4 different regions have used. These soils are named as Adıyaman (A), Gaziantep (G), Kilis (K) and Şanlıurfa (Ş). Regions to be sampled are predetermined and it has been taken into account that natural soils have different gradations. The organic soils on sample region have been cleared. Natural soil samples have taken from region where it excavated 150-200 cm with help of a dipper. Samples taken have carefully transported to pilot facility. The parameters of natural soil have determined by field and laboratory experiments.

Figure 3.1 Excavation of soil samples.

3.2.2 Wastewater

Experimental wastewater has obtained from the influent water of GASKI Kızılhisar wastewater treatment plant located in Oğuzeli/Gaziantep district. The facility has been designed for the treatment of domestic wastewater and waste landfill area wastewater. The average analyses values (mg/L) of facility influent water quality for 2019 year are given in Table 3.1.

Table 3.1 Average analyzes of facility influent water quality in year 2019.

Parameters	Unit (mg/L)
SS	285.56
COD	493.76
TN	67.92
TP	4.99
pH	7.74

3.2.3 Soil - Water Interaction

One of the most important parameters affecting the index and engineering properties of soils is pore water and its characteristic. The behavior of soils against water and amount varies depending on whether the ground is fine-grained (clay-silt) and coarse-grained (sand-gravel). Soil-water relationship plays an important role in use of soils in field of civil engineering. To understand many problems encountered in practice and to develop engineering solutions, the effects of water on soil behavior need to be investigated. The performance of most soils depends on water content and plasticity index. For example, the event of swelling-shrinkage on clayey soils depends on the amount of water in soil pores.

The combination and amount of water passing by soil essentially initiates a chemical process in environment through which it passes. This chemical process is relatively fast cation exchange reactions with soil colloidal materials and slow acid hydrolysis reactions that can decompose primary minerals (Bache et. al., 1984). Different compositions corresponding to the flow rate of water and the time of contact with soil can significantly change the structure of soil.

3.2.3.1 Water in the soil

The pores between grains that make up a soil mass can been partially or completely filled with water. Water in a soil mass is found in different conditions (Figure 3.2).

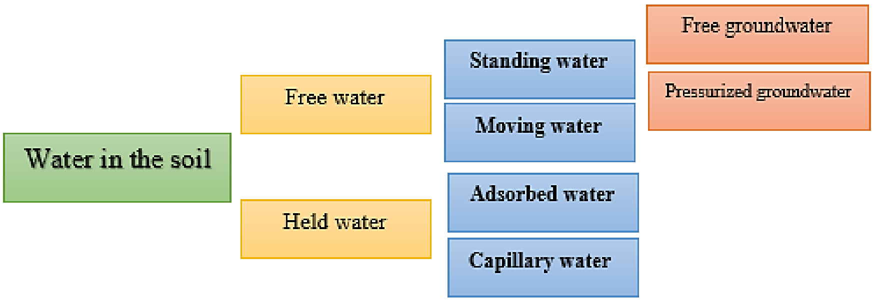


Figure 3.2 Simple classification of soil water.

Water can do both a sliding and binding effect between soil grains and therefore can affect strength of soil. When a soil is completely dry, it cannot be compacted to maximum density due to friction between soil particles. As water content increases, water lubricates soil, allows it pass more easily transition to a compact state (Ghosh, 2013). The relationships between soil and water can be explained by three main concepts: capillarity, permeability, seepage.

Capillarity, the movement between a capillary pipe and water is called capillary motion. It is known that the rise of water in a capillary pipe depends on properties of liquids and solids (Mitropoulos, 2009). Water rises in a kind of capillary pipe formed by pores between soil grains.

Specifically, the capillary effect provides more useful information in predicting soil-water interaction of unsaturated soils. Capillary water effect may be more pronounced among coarse porous sand-silt soil particles. In fine-grained clay soils, water will form bond. Here, the characterization of bond water affecting behavior of unsaturated soil becomes important (Guo et. al., 2019).

Permeability can be defined as property of soil to convey water and air through interconnected cavities. Permeability is a measure of porosity that allows liquids and air to pass through a soil (Chegenizadeh and Nikraz, 2011). There are many factors that affect permeability of soils. These counted as factors stratification of soil, grain size and distribution, mineralogical structure, void ratio, degree of saturation, viscosity of water flowing in soil, adsorbed water and properties, temperature, etc.

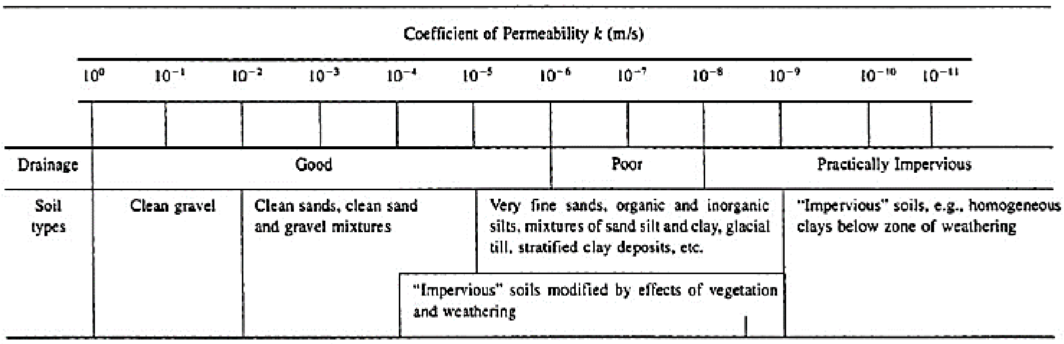


Figure 3.3 Permeability and drainage characteristics of soil (Terzaghi et. al., 1996).

The flow of water in soil can be described as seepage. Seepage is phenomenon of moving of liquid in a permeable environment.

3.3 Method and Test Program

3.3.1 Research Model and Area

Experimental field of study is located in the district of Oğuzeli/Gaziantep/Turkey. The study area is GASKI Kızılhisar Wastewater Treatment Plant and has an area of approximately 3000 m^2. The study area is located at 36.940708 latitude and 37.441172 longitude location. The study area is dry and hot in summer and rainy and temperate in winter. The average annual temperature is 14.9 and the average annual rainfall is 552.8 mm (mgm.gov.tr).

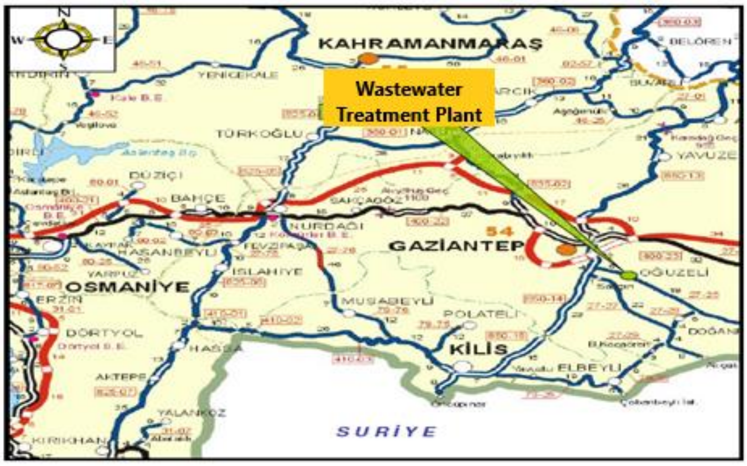


Figure 3.4 Location notification map.

A pilot plant has been arranged in study area at a single point (treatment plant influent water). The pilot plant consists of a pump thrown into influent water pool, 2 sedimentation tanks and soil columns.

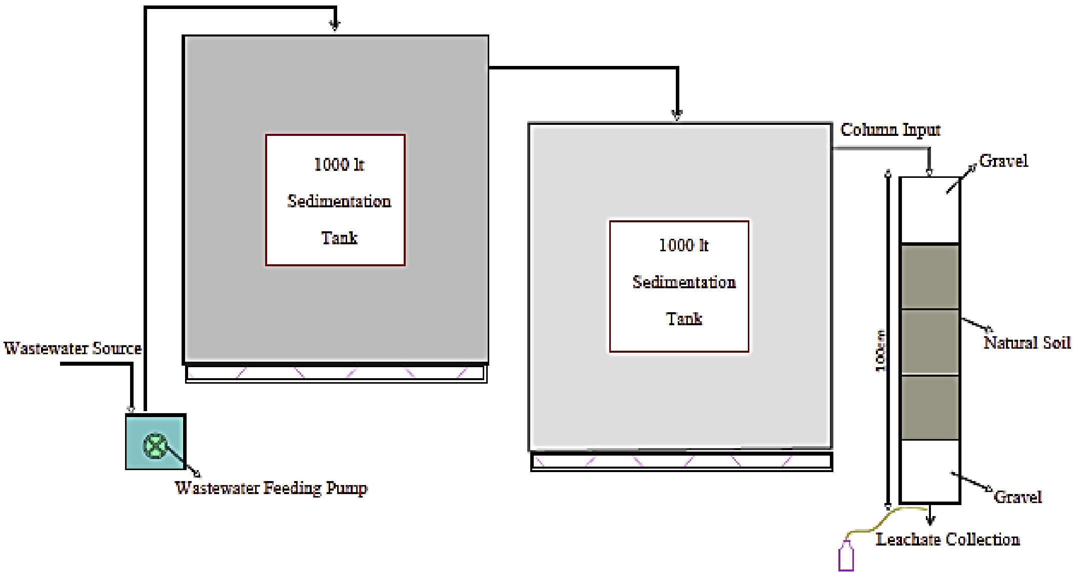


Figure 3.5 Schematic demonstration of subsurface wastewater infiltration systems.

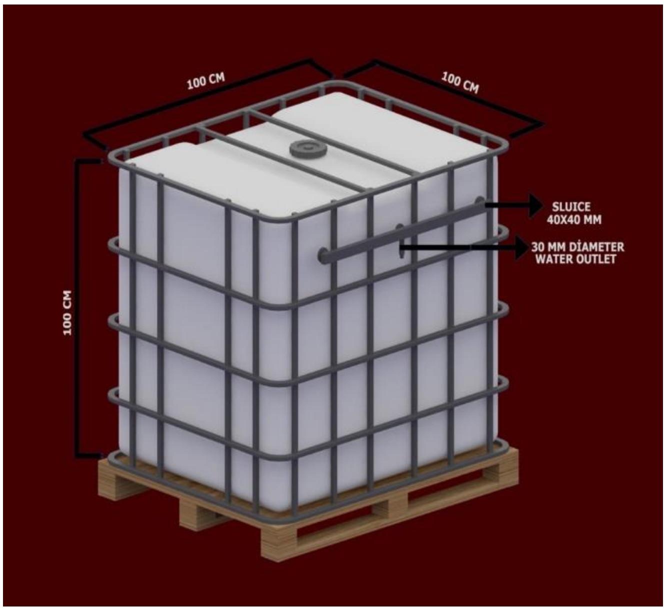
Wastewater from the treatment plant influent water was first pumped into a septic tank with a capacity of 1000 L and first sedimentation was performed. When the amount of sediment in tank is fixed, it was filled up the 2nd septic tank with a plastic hose of 30 mm diameter from the overflow level of the 1st septic tank. From the overflowing level of the 2nd septic tank, wastewater was given from the upper part of plexi-glass transparent soil column which is 20 cm in diameter and 100 cm high. This water shows character of wastewater intended to leak into soil. Then, analyzes have made to determine soil properties and water quality.

3.3.1.1 Soil Column

Soil column has an inner diameter of 19.4 cm, outer diameter of 20 cm and height of 100 cm. In natural water content, soil columns have created for 4 different soil samples and each natural soil has subjected to similar experimental processes. The columns have filled in such a way to have all characteristics of natural soil and to preserve the existing formation. In order to prevent the soil samples placed in pipes from being affected by weather conditions such as sun and rain, column surfaces have covered with dark filter paper. The bottom part of soil column consists of from a teflon base with a diameter of 22.5 cm. There are sieves with 8 mm or 5 mm diameter inside base. Similar sieves locates at the top of column to distribute wastewater evenly. Figure 3.6 presents soil-column apparatus.

3.3.1.2 Sedimentation Tanks

Sedimentation tanks with a capacity of 1000 L have been used to ensure separation of settleable solids from wastewater and to balance the variables that may be in flow rate and pollution load.



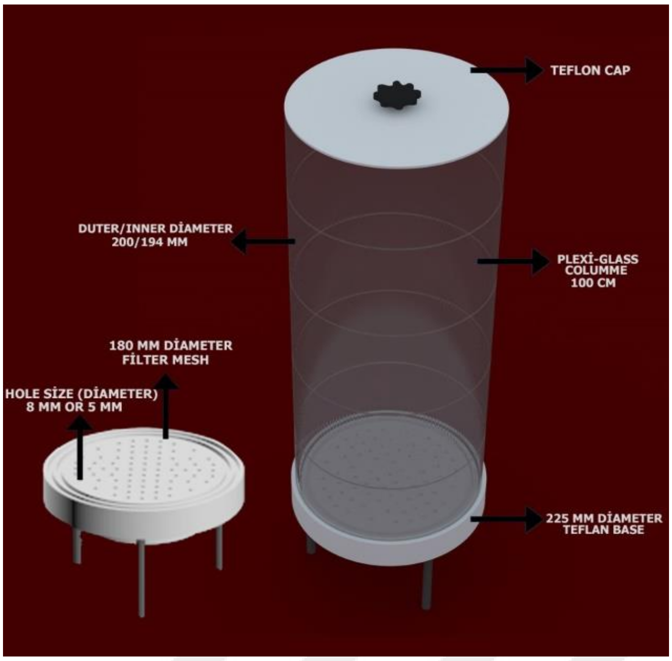


Figure 3.6 Autocad 3D max modelling for sedimentation tank and soil column.

3.3.1.3 Field Data Collection

The influent water injected from the top of soil column has drained through 8 mm or 5 mm diameter sieve at bottom of soil column. Wastewater influent and effluent the soil column has collected on the specified days and times.

Soil analyses have carried out before and after soil column is created. Data has collected under different soil properties and different hydrological regimes.

Table 3.2 Soil column test profile.

Soil-column experiment	**A**			**G**			**K**			**Ş**		
Plexi Glass Column (cm)	100			100			100			100		
Soil Thickness (cm)	60			60			60			60		
Soil Weight (g)	30150.43			31214.57			32810.77			33520.19		
Drainage (cm)	20 + 20			20 + 20			20 + 20			20 + 20		
Type of Soil	Natural			Natural			Natural			Natural		
Saturation Conditions	Unsaturated			Unsaturated			Unsaturated			Unsaturated		
Water Type	Domestic Wastewater			Domestic Wastewater			Domestic Wastewater			Domestic Wastewater		
Injection Method	Continuous			Continuous			Continuous			Continuous		
Injection Flow Rate (L/day)	36	18	9	36	18	9	36	18	9	36	18	9
Experiment Time (days)	23			23			23			23		
Experiment Season (month)	August-September			February- March			May-June			July-August		

Effective working time of soil-columns was 23 days. The water pumped from the plant influent water into the sedimantation tanks was subjected to a retention period of approximately 2 days. Then a total of 3 columns formed from each natural soil were fed with wastewater at 3 different flow rates (9, 18 and 36 L/day). Flow variables were determined in relation to the total filtration volume.

Water samples from the drainage effluent present in the lower parts of the column were collected at average 48 hour intervals. The minimum of 10 column effluent water samples were taken from different flow rates (9, 18 and 36 L/day) for each soil column. Chemical oxygen demand (COD), suspended solids (SS), conductivity and pH analyzes were performed for every 10 samples taken from the soil columns. Total nitrogen (TN), total phosphate (TP), hardness and sodium absorption values (SAR) analyzes were performed 5 times as 1, 3, 5, 7 and 10. samples (Table 4.1).

Before each soil column was filled, some physical, chemical and mechanical properties of natural soils were determined. At the end of 23 days of wastewater filtration, the soils were carefully removed from columns. Atterberg limit, compaction, specific gravity, permeability, unconfined compression test (UCS), scanning electron microscope (SEM) and element analyses of natural soils were performed (Table 4.1).

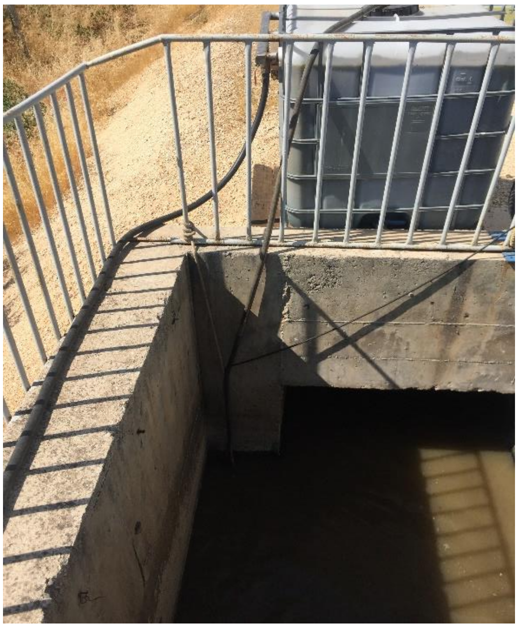


Figure 3.7 Taking wastewater from the influent water of the plant to the first sedimentation tank by pump.

Figure 3.8 Wastewater passage from the first sedimentation tank to the second sedimentation tank.

Figure 3.9 Feeding soil columns with wastewater after the second sedimentation.

3.3.2 Test Program for Geotechnical Properties of Soil

This title presents details of the made analyzes and measurement equipment for 4 natural soils before and after introduced wastewater into soil.

3.3.2.1 Grain Size Distribution

3.3.2.1.1 Size Analysis Using Wet Sieving Method

This test method is related to grain diameter distribution of fine and coarse size material and covers determination of total amount of clay and silt in soil by washing. Wet Sieving is the elimination of water-soluble matters and material fine than 75 ηm (No.200) by removing from soil. The material dried in oven after washing is sieved from sieve series in accordance with American Society for Testing and Materials (ASTM), D422-02 and D421-85 standards. The sieving was proceed for at least 10 minutes with mechanical shaking device and the weight of amount remaining in each sieve was recorded. Then the percentage of total material passed through each sieve was calculated. The grain size distribution greater than 0.075 mm was drawn in granulometry curve.

Determination of the quantity of material passing a 75-ηm (No.200) sieve by washing as follows;

$$X = \frac{(Y-Z)}{Y} \, x \, 100 \tag{3.1}$$

Where; X: Rate of material finer than a 75-ηm (No.200) sieve after washing

Y: Original dry mass of sample (g)

Z: Dry mass of sample by washing (g)

3.3.2.1.2 Hydrometer Analysis

Hydrometer analysis is a process in which sizes of clays and silts under 75 ηm (No.200) sieve. The calculation method is based on Stocks Law. In this study, 4 different hydrometer analysis tests have conducted for each soil type following the ASTM D7928-17 and ASTM D422-63(2007)e2 (E100) procedures, using a hydrometer model 152H.

Figure 3.10 Hydrometer test in laboratory.

For the experiment, 50 g of soil sample was taken from No.200 (75 ηm) sieve material. A solution was prepared with 250 g sodium hegzametaphosphate ($(NaPO_3)_6$) and 1000 ml distilled water. This solution was taken 100 g and mixed with 50 g soil sample. The suspension obtained was put into a high speed mixer and mixed for 5-10 minutes. The mixed sample was completed with distilled water to form a 1000 ml solution. Immediately after this process; the hydrometer was plunged into suspension cylinder and hydrometer and temperature readings were started to be measured. Thus, the density changes of suspension at varying time intervals were measured and the percentage of amounts remaining in suspension and the grain diameters corresponding to these percentage were calculated using equations according to Stokes Law. Granulometry curve was generated as a result of sieve and hydrometer analysis.

3.3.2.2 Scanning Electron Microscope (SEM)

Scanning electron microscopy (SEM) is a microscope that provides information about the sample external morphology (texture), chemical composition and crystal structure and orientation of sample by sending an electron beam composed of high energy electrons to surface of micro and nano sized materials.

SEM analysis was performed in order to obtain high magnification and solubility images of wastewater leaked and non-leaked soil samples used in thesis study. The test samples prepared for SEM analysis were completely dried in the oven at 105°C for 24 hours. Then dried samples was sieved through No.40 sieves (0.425 mm). Imaging analyses with SEM was carried out in the Center for University and Industry Collaboration, Kahramanmaras Sutcu Imam University. ZEISS/EVO LS10 model desktop SEM device was used for imaging.

3.3.2.3 Specific Gravity

Specific gravity is defined as the ratio of the density of the substance to the density of a reference substance at a specified conditions of temperature and pressure; quantitatively, it's ratio of mass of a substance to its volume. The specific gravity of soil grains is need to know for some calculations of soil mechanics. It is important to study the balance against deformations that may occur in soil and to determine compaction and consolidation properties of the soil.

Specific gravity can be easily determined by laboratory experiments by means of ASTM D854-14 standard test methods. These test methods contains the determination of specific gravity of soil solids passing the 4.75 mm (No.4) sieve by means of a water pycnometer. The water pycnometer was first weighed in the experiment and its weight recorded (M_1). Then at least 10 g of soil sample was filled into pycnometer and weighed (M_2). In third stage, the pycnometer filled with soil sample was mixed with water and weighed (M_3). Finally, the water filled weight of pycnometer was determined (M_4). The specific gravity is calculated as follows.

$$Gs = \frac{\gamma L\ (M2 - M1)}{\gamma w\ [(M4 - M1) - (M3 - M2)]} \qquad (3.2)$$

Where; γ_L: The specific gravity of the liquid used in the test temperature, g/cm^3

γ_w : The specific gravity of water at test temperature, g/cm^3

3.3.2.4 Consistency of Soil (Atterberg Limits)

Atterberg limits, known as consistency limits, specify the hardness and softness states of cohesive soils. It enables the identification of fine grain soils in varying water content. It also gives basic information showing the structure and classification of soil. As the amount of water in soil increases, the soil indicates change in a wide range from a very solid state to a liquid consistency. These changes create differences in many engineering properties such as soil strength, hydraulic conductivity or permeability, compaction and deformation under load. In this study, liquid limit, plastic limit and plasticity index of soils were tested on the basis of ASTM D4318-00 standards. Depending on test results, the samples were classified according to the Unified Soil Classification System (USCS).

The liquid limit, using the casagrande method as common was performed only on that portion of a soil that passes 425 ηm (No.40) sieve. In this test method, approximately 200 g of sample was taken into a container and water was added gradually. The well mixed sample was placed in batting bowl of the Casagrande liquid limit tool and divided into two equal parts with groove opening knife. The crank arm was rotated at a speed of 2 blows per second. The experiment was terminated by combining the sample divided into two equal parts at 13 mm at bottom of container. The number of blows was recorded and water content was determined by taking samples from area where soil was closed by flowing. The experiment was repeated at least 5 times in different water content. A semi-logarithmic graph of water contents-blow numbers obtained from each experiment was created. A line was drawn through points obtained. The LL was found as water content equivalent to 25 blows.

The plastic limit was found as water content on which the sticks descend without breaking a diameter of about 3 mm, when turning the soil into a stick on a glass surface. The plasticity index values of samples were found by subtracting the LL and PL.

Figure 3.11 Determination of atterberg limits in laboratory.

3.3.2.5 Bulk Density

Unit weight or bulk density is calculated the total weight of the soil divided by total volume. The total weight of soil contains also weight of water. The total volume includes the volume of solid as well as water and air volumes.

The mass density test performed on undisturbed sample under land conditions was determined by penetrating sampling tubes into soil. During measurement, excess material on tubes was properly scraped and cleaned. Then the total weight (W) and total volume (V) of tubes filled with soil were determined. This method should be applied to soils that would protect it shape during measurement process. Bulk density (γ_n) was determined by formula the W/V. Bulk density of natural soils is given in the Table 3.3.

Table 3.3 Bulk density of natural soil.

Soil type	**A**	**G**	**K**	**Ş**
γ_n (g/cm^3)	1.70	1.76	1.85	1.89

3.3.2.6 Compaction Test

Compaction is process of reducing the pore volume within soil with a mechanical energy and increasing the density of soil. Compaction is divergently definition of water content on soil. Compaction is closely related to permeability, shear strength, bearing capacity, settlement and deformation properties of soils.

The purpose of compaction test is to determine the optimum water content (ω_{opt}) and maximum dry density (γ_{kmax}) of soil. In this study, compaction characteristics was determined by conducting standard proctor experiment in scope of ASTM D1557 test methods. Standat proctor test is process of compacting three layers soil in a standard mold with an internal volume of approximately 1000 ml and compacting each layer with a 2.5 kg rammer in 25 blows. The experiment was repeated at least 5 times in different water contents. The ω and γ_n of each compacted soil was calculated. The dry density (γ_k) of soil was calculated from the following equation.

$$\gamma k = \frac{\gamma n}{1 + \omega} \tag{3.3}$$

The values of water contents obtained from experimental results and corresponding to its were processed on a graph paper. A smooth curve was drawn from points obtained and the greatest values on that curve was found. These values provided determination in ω_{opt} and γk_{max} of soil.

Figure 3.12 Standard compaction test in laboratory.

3.3.2.7 Permeability Test

Permeability can be defined as the ability of soil to transmit water and air through its interconnected pores. Permeability is a measure of porosity that allows liquids and air to pass through a soil. This measure is of great importance in geotechnical engineering.

Permeability is one of the oldest experiments made for soils (Chegenizadeh and Nikraz, 2011). Permeability test is performed to determine the permeability coefficient of soils. The permeability test method is applied falling or constant head according to soil type. Generally, permeability testing at constant head on coarse-grained soils and at falling head on fine-grained soils are performed. In this study, falling head permeability test was performed.

The test samples prepared in optimum water content were compressed in three stages by applying standard compaction energy to the permeability test cell with a diameter of 100 mm and a height of 130 mm. The compressed test cell was released into water overflow tank (Figure 3.13). After the necessary connections were made, water was filled into pipes of different diameters each 1500 mm long on the wooden stand and water was flowing through soil. As time passed, the amount of water passing through cross section area of soil was provided a stable flow. Water heights readings were taken and recorded at various times during experiment. The permeability coefficients of soils were calculated from following equation.

$$k = \frac{2.3\mathrm{aL}}{\mathrm{At}} \log\left(\frac{H}{H-\Delta H}\right) \tag{3.4}$$

Where; H: The first water level in pipe, cm

a: Pipe area, cm^2

A: Permeability test cell area, cm^2

L: Sample height, cm

t: The passing time, sn

ΔH: Water level difference between first reading and last reading, cm

Varying water heights for each measurement taken at different time intervals were recorded and permeability coefficients were calculated separately. The permeability coefficients of soils were determined by taking the average of calculated coefficients.

Figure 3.13 Falling head permeability test in laboratory.

3.3.2.8 Unconfined Compression Test

Unconfined compression test is a laboratory testing method conducted to assess the mechanical properties of generally fine-grained soils. This test provides a calculation of the undrained shear strength and stress-strain characteristics of soils. Due to express the just axial pressure that a specimen can bear under unconfined stress, Unconfined compression test is also known as unconfirmed compressive strength (UCS). UCS is a parameter commonly used in geotechnical engineering.

In this test method, test samples cylindrical prepared according to ASTM D2166 standard should be length to diameter ratio (L/D) 2.00. The disturbed test sample was prepared by compressing gradually in optimum water content. The prepared sample was placed in device and started loading at constant speed. During each axial load increase, the length of sample occurred shrinks. The test was terminated when the axial load increase started to show a decrease and the sample was broken. The stress (σ)-strain (ε) curve of sample was determined. The greatest value of axial stress gave the UCS (q_u) of soil.

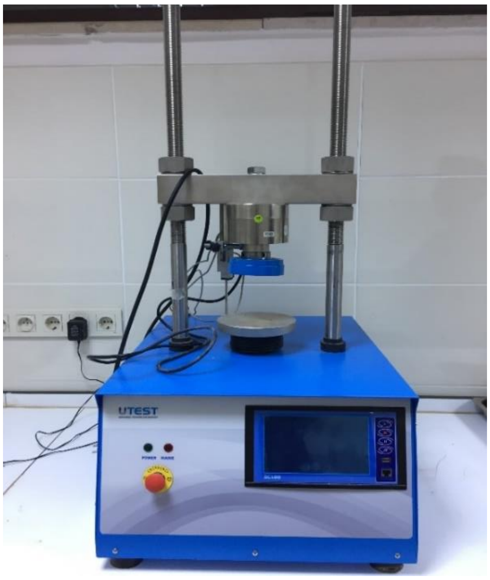


Figure 3.14 Unconfined compression tester.

3.3.2.9 Determination of Soil Water Content

Generally, water content of soil is defined as the rate of weight of water held in soil to dry soil. The weight of water in soil was determined by the difference in weight before and after drying soil. Dry weight of soil was determined by drying oil in an oven at 105°C±5 for 24 hours. Water content of natural soils are given in Table 3.4 as %.

Table 3.4 Water content of natural soils.

Soil type	A	G	K	Ş
Water Content (%)	9.2	22.1	5.5	7.6

3.3.2.10 Determination of Soil Porosity

Porosity is among the important physical properties of the soil. It is a parameter that can be associated with the permeability of soil. Also, the density of the soil is related to its porosity.

$$n = 1 - (\frac{\gamma n}{\gamma s}) \tag{3.5}$$

The porosities of natural soils used in the experimental study were calculated using the above equation.

Table 3.5 Porosity of natural soils.

Soil type	A	G	K	Ş
n (%)	38.30	34.40	29.80	30.40

3.3.2.11 Soil Elemental Analyses

The natural contents of elements in soils that have not undergone any intervention depend on the geomorphic development process of the soil. But various anthropogenic activities contribute significantly to the change in the concentration of environmental elements, especially soil (Matong et. al., 2017). Therefore, soil element analyses were determined to investigate the likely change of the soil structure due to sewage effluent disposal (Dawes and Goonetilleke, 2003).

The samples prepared for the experiment were air dried. Then, it was sieved through a 0.425 mm sieve. Soil samples were submitted to the University of Harran Application and Research Center for Science and Technology for the following analyses: soluble potassium (K), phosphate (P), calcium (Ca), sodium (Na), magnesium (Mg) and nitrogen (N). Soil analyses were measured in using Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). Nitrogen was measured as a percentage with an elemental analyzer. Changes in soil chemical properties within the course of treatments were examined using these analysis results.

3.3.3 Test Program for Wastewater

This title presents the conducted analyses and methods of determining wastewater characterization after passing the 1st and 2nd sedimentation tanks of wastewater treatment plant influent water and effluent soil column.

3.3.3.1 Suspended Solids (SS)

Suspended solids (SS) refers to a colloidal solution or small solid particles that can remain as suspension in water. It should not be confused with solids that can precipitate directly. SS is a parameter indicating water quality. High amounts of SS cause physical contamination of water. The amount of SS in water is directly proportional to turbidity of water. It has a direct impact on the cost of wastewater treatment.

The main system of SS determination is the infiltration setup. The SS filter paper dried in test was weighed with precision balance and its weight was recorded (A). The weighed filter paper was placed in infiltration setup and the volume of which was known amount discharged into wastewater filter funnel (V). The vacuum pump was operated until the sample in filter funnel was finished. Then the filter paper was taken from infiltration setup and subjected to drying process. After drying at 105°C, the filter paper was carefully placed on precision balance and weighed (B). The amount of SS was calculated with following formula.

$$SS = \frac{(B-A)x\ 1000}{V} \ \text{(mg/L)} \tag{3.5}$$

Figure 3.15 Sample in the filtration funnel.

Figure 3.16 Filter paper in the oven.

3.3.3.2 Chemical Oxygen Demand (COD)

Chemical oxygen demand is the most important test parameter used to determine the pollution degree of domestic and industrial wastewater. COD is an indicator of the amount of oxygen that can be consumed for the oxidation of organic matters in a solution that can be measured. The amount of oxygen consumed in solution volume is expressed in milligrams per liter (mg/L) or grams per cubic meter (g/m^3).

COD value is of fundamental importance in determining the harmful potentials of wastewater, determination degree of contamination and pollution of water and wastewater sources, design, planning of wastewater treatment plants, control and operation of treatment efficiency.

In the scope of study, COD values were calculated by closed reflux colorimetric method. Before starting the experiment, suspended solids in wastewater sample were removed and the sample was made homogeneous. 2.5 ml was taken from sample and put into glass tubes. 1.5 ml standard potassium dichromate solution ($K_2Cr_2O_7$) and 3.5 ml sulfuric acid reagent were added to sample. The prepared sample has exposed to heat at 150°C in the thermoreactor for two hours. Then the tubes were cooled at room temperature. COD measurements of samples by placing spectrophotometer the cooled tubes were made.

Figure 3.17 Disintegration sample in thermoreactor and spectrophotometer.

3.3.3.3 Total Nitrogen (TN)

Nitrogen (N) is an element that makes up about 78% of the atmosphere. Nitrogen, which is involved in the structure of amino acids, proteins, nucleic acids, hormones and vitamins, is an essential component for living life. All living cells need N for survival and reproduction. But living things cannot directly benefit from free nitrogen found in nature. In order to nitrogen to be used by living things, it needs to be converted into nitrogen compounds through various processes. The most important compound forms of N are ammonium (NH_4^+), ammonia (NH_3), nitrate (NO_3^-) and nitrite (NO_2^-) ions. These are forms of nitrogen that need to be measured in surface water and wastewater (Samsunlu, 2011; Doğanay, 2014).

Nitrite (NO_2^-) is an ion that is very rare in water since it is a transition phase. There are no high concentrations of nitrate (NO_3^-) in domestic wastewater (Cirik and Eskikaya, 2018). In this study, total nitrogen was analyzed with ready nitrogen cell test kits. The measurement method of the test kits is photometric and the measurement range is 0.5-15.0 mg/L N.

3.3.3.4 Total Phosphorus (TP)

Another pollution parameter that causes problems in direct discharge of wastewater into the receiving environment is phosphorus. Phosphorus (P) is often found in natural water and wastewater as phosphate (PO_4^{-3}). Phosphate sources may be a wide variety. For example, fertilization in agricultural areas, textile industry, industrial cleaning materials etc.

In the aquatic ecosystem, phosphorus can be found suspended or dissolved in water. In our study, TP was found by determination of all forms of phosphate by some chemical reaction. TP was determined with test kits containing ready-to-use reagent mixtures. Phosphate test kits have a measurement range of 0.01-5.00 mg/L PO_4-P and 0.03-15.3 mg/L PO_4. It is in the standard of ISO 6878_2004, DIN EN 6878/D11.

3.3.3.5 Conductivity

Another parameter used in determining water quality is conductivity. Conductivity is a numerical expression of water ability to carry electricity. The conductivity of water can depend on the concentration of ions dissolved in water, the charges and mobility of ions and the measurement temperature. Siemens/cm is used as unit of measurement (S=Siemens=Ohm^{-1}). However, it is used smaller subunits of miliSiemens/centimeter (mS/cm) and microSiemens/centimeter (µS/cm) in treatment. In this study, the conductivity of water was easily measured with Hanna Instruments HI-2315 Conductivity Meter.

3.3.3.6 Hardness

Multivalent cations (Ca^{+2}, Mg^{+2}, Mn^{+2}, Fe^{+2}, Sr^{+2} etc.) available in water are called hardness ions. The water containing the dissolved salts of these cations forming hardness is generally hard water. However, cations other than Ca^{+2} and Mg^{+2} do not much effect hardness of water as its are less in natural water (Boysan and Şengörür, 2009). Therefore, hardness in water is expressed in terms of concentration of calcium carbonate ($CaCO_3$) equivalent to the sum of dissolved concentrations of Ca^{+2} and Mg^{+2}. Its unit is mg/L.

Table 3.6 Classification of water hardness, $CaCO_3$ (mg/L) (Samsunlu, 2011).

$CaCO_3$ (mg/L)	**Degree of hardness**
0-75	Soft
75-150	Moderately Hard
150-300	Hard
300 and above	Very Hard

In this study, elemental analyses in wastewater were performed with ICP-OES device and hardness in water was calculated with the following formula.

$$Total\ Hardness = [2{,}497\ x\ Ca^{+2}] + [4{,}118\ x\ Mg^{+2}] \quad (3.6)$$

3.3.3.7 pH

pH value is a unit of measure that expresses the state of being acidic (H^+) or basic (OH^-) of a solution. In other words, pH value indicates the concentration of hydrogen ions (H^+) contained in water. The pH density in water varies between 0 and 14. Water is neutral at pH 7, that is, the concentration of hydrogen ions (H^+) in water equals the concentration of hydroxide (OH^-) ions. If the (H^+) ions in water increase, the pH of water decreases and water becomes acidic. If the hydroxide (OH^-) ions in water increase, the pH of water rises and water becomes basic. pH value is a parameter in wastewater treatment that affects the living conditions of microorganisms and the functioning of chemical reactions. In the study, pH measurements were automatically measured by Hanna Instruments HI-2211. Measurements were made instantaneously.

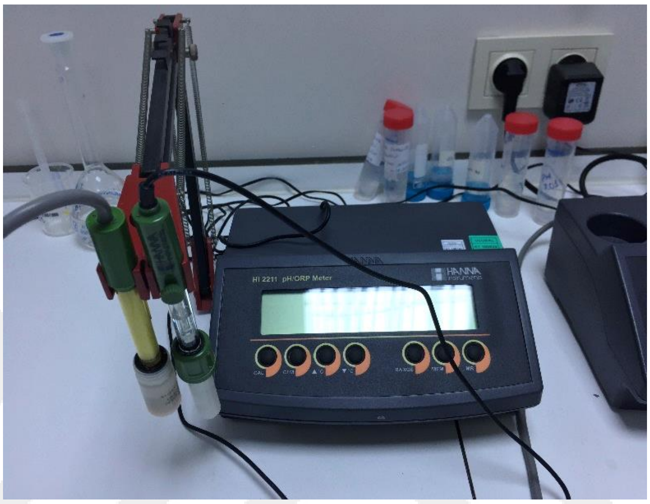


Figure 3.18 Conductivity and pH measurements.

3.3.3.8 Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio (SAR) is an irrigation water quality parameter. The ion exchange of cations in soil structure with the main alkali in irrigation water is an indication of whether or not the water will be used in agricultural irrigation. Also, the SAR value is used to estimate the infiltration rate problem that will occur in soil (Richards, 1954). SAR is calculated by following equation.

$$\mathrm{SAR} = \frac{\mathrm{Na+}}{\sqrt{\frac{[\mathrm{Ca+2}] + [\mathrm{Mg+2}]}{2}}} \tag{3.7}$$

In case of high Na^+ in soil texture, soil particles can be separated from each other and the soil can have a granular structure. This condition can affect the permeability of soil and can cause infiltration problems. Negative effects of sodium on soil structure can be estimated by SAR (Bourrie, 2014).

Optima 8000 ICP-OES device was used for elemental analyses of 0.45 micron filtered wastewater solutions in the experiments. The elements in the solution were directed to mass filter after being ionized in the ICP device. Ions separated according to mass/load ratios in mass spectroscopy and measured by the detector. Elemental analyses for determination of hardness and SAR values provided information about some chemical elements found in wastewater. The element potassium (K) was measured as well as the elements calcium (Ca), magnesium (Mg), sodium (Na).

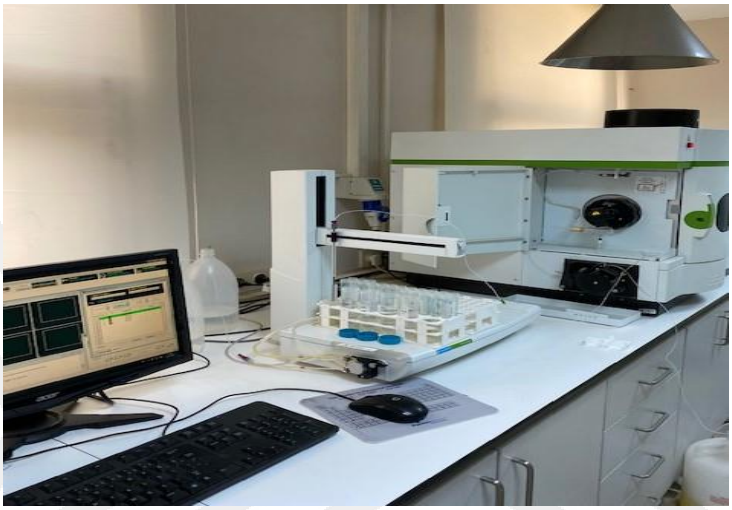


Figure 3.19 ICP-Optical Emission Spectroscopy analysis.

3.3.4 Limitations of the Study

As stated in the previous sections, it has aimed to evaluate the changes in soil structure caused by domestic wastewater reaching the soil directly or indirectly, the transformation of wastewater in soil and the transport of leached water to groundwater in this study. Excavation, transportation and placing in column of natural soils used in test was paid attention purity minimum 95%. Soil columns were filled in natural unit volume weights and natural water content. Repeating each column was equal properties. Wastewater leakage flow was started under unsaturated system conditions. Seasons were recorded during test. In the study, the local natural soils of Adıyaman (A), Kilis (K) and Şanlıurfa (Ş) provinces were taken and brought to the province of Gaziantep (G) in order to represent different regions by infiltration. Due to the close socio-economic and cultural etc characteristics of the region, one type wastewater (Gaziantep wastewater plant influent) was used.

Test methodology, leachate quality, contaminant removal factors from wastewater, investigation of data changes in natural soil, interaction of some contaminants in leachate with soil, identification of transformation products of leachated water, examining structural characteristics of different soil types etc. provides information about. Moreover, it can help to decide on applicability of the method in field. However, it does not predict leakage behavior in field or field conditions due to the fact that there is not exist only vertical movement of water in soil. In addition, the direction and magnitude of flow can change depending on time. Futhermore, soil structure can be constant changing throughout soil formation. The values that can reach groundwater are quite difficult to measure qualitatively.

It can be said that the results of study will be efficient in evaluating the results of the systems operating in short term in different infiltration areas, whereas they do not represent long term studies.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

This chapter covers the results of soil and wastewater laboratory tests performed with the test methods given in chapter 3. This chapter includes the experimental results of natural soil samples and wastewater leaked soil samples subjected to wastewater filtration as well as the analyses results of wastewater influent and effluent the soil column. The results of the experiments were interpreted by supporting graphs, tables and figures. The experiments were carried out at the Hasan Kalyoncu University Environmental Application and Research Center and Civil Engineering Geotechnical Laboratories.

Table 4.1 Soil and wastewater tests preview.

Analyzes for wastewater influent and effluent	**Soil tests before and after wastewater application**
Total N	Soil Classification (Sieve Analysis-Hydrometer)
Total P	Atterberg Limits
Suspended Solid (SS)	Compaction Test
Chemical Oxygen Demand (COD)	Specific Gravity
Hardness	Permeability Test (Falling Head Test)
pH value	Unconfined Compression Test (UCS)
Conductivity	Scanning Electron Microscope (SEM)
Sodium Adsorption Ratio (SAR)	Soil Elemental Analyses

4.2 Experimental Results of Geotechnical Properties of Soil

4.2.1 Grain Size Distribution

The % sand and gravel ratios of natural soils used in the study were found as a result of sieve analyses and % clay and silt ratios were found as a result of hydrometer analyses. The grain size distribution curve of the soils was obtained by combining the results of two analyses. Analysis results are shown in Figure 4.1.

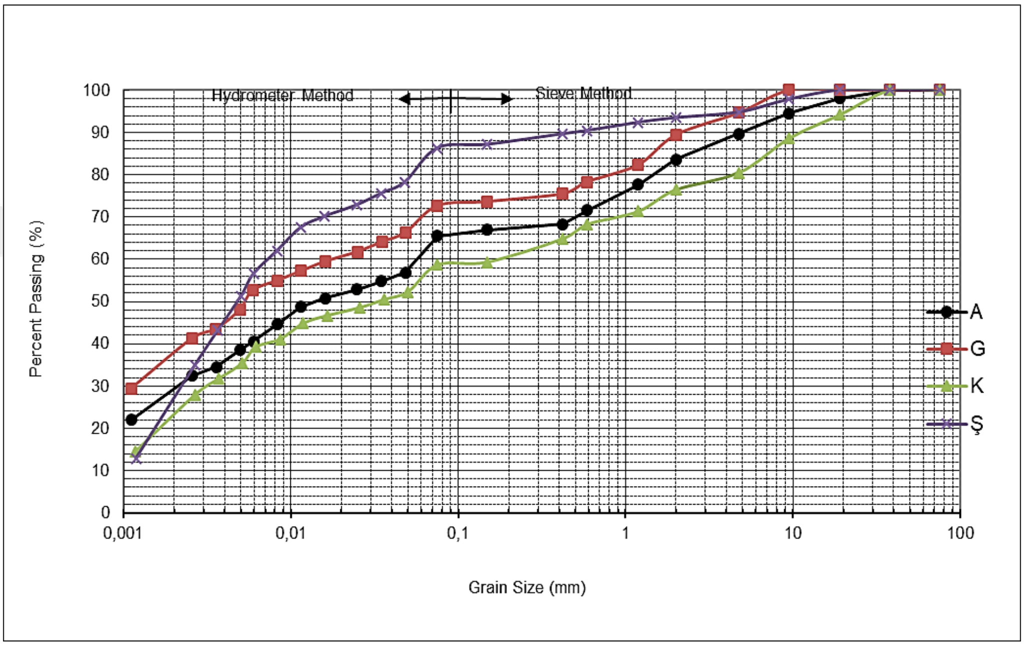


Figure 4.1 Grain size distribution.

As a result of sieve and hydrometer analysis of A natural soil, 10.27% gravel, 24.24% sand, 36.10% silt and 29.39% clay have found. According to the USCS-Unified soil classification system, when the grain size analysis is evaluated together with consistency limits, it has been determined that the soil is CL (Low plasticity clay) type.

As a result of sieve and hydrometer analysis of G natural soil, 5.37% gravel, 22.00% sand, 34.91% silt and 37.72% clay have found. According to the USCS-Unified soil classification system, when the grain size analysis is evaluated together with consistency limits, it has been determined that the soil is CH (High plasticity clay) type.

As a result of sieve and hydrometer analysis of K natural soil, 19.56% gravel, 21.79% sand, 35.46% silt and 23.19% clay have found. According to the USCS-Unified soil classification system, when the grain size analysis is evaluated together with consistency limits, it has been determined that the soil is CL (Low plasticity clay) type.

As a result of sieve and hydrometer analysis of Ş natural soil, 5.22% gravel, 8.46% sand, 59.17% silt and 27.15% clay have found. According to the USCS-Unified soil classification system, when the grain size analysis is evaluated together with consistency limits, it has been determined that the soil is CL (Low plasticity clay) type.

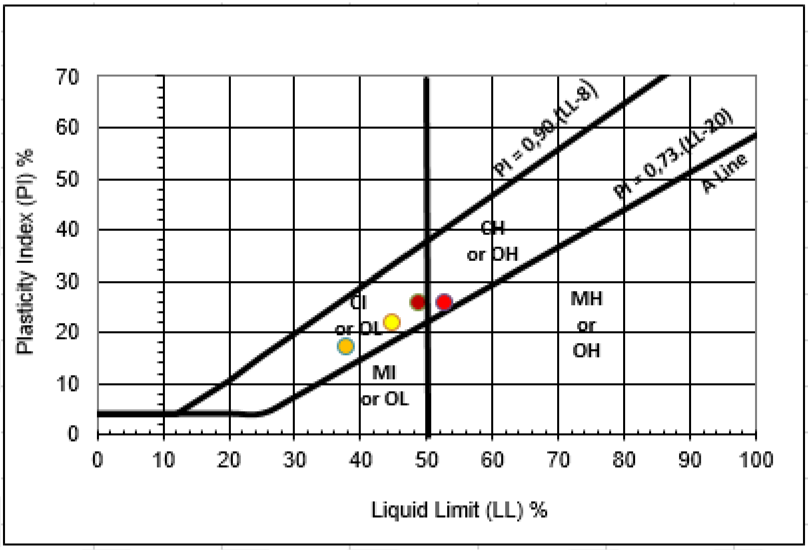


Figure 4.2 USCS-Plasticity chart showing of natural soils.

4.2.2 Atterberg Limits (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 and Sridharan, 1985; Muhunthan, 1991). Therefore, Atterberg limits can be used as a precursor to predict many important properties of soils. Liquid limit and plastic limit experiment results of natural soils conducted according to American Society of Testing Materials ASTM D 4318-00 (2003) standard Table 4.2 are given.

Table 4.2 Atterberg limits test results.

Soil Type	(%) LL		(%) PL		(%) PI	
	Before leaking	After leaking	Before leaking	After leaking	Before leaking	After leaking
A	48.9	47.1	23.4	24.5	25.5	22.6
G	53.4	51.2	27.7	28.0	25.7	23.2
K	38.3	42.1	21.3	22.3	17.0	19.8
Ş	45.1	48.9	23.4	23.8	21.7	25.1

Table 4.2 is shown the test results of natural soils before and after leaking wastewater. When Table 4.2 is examined, LL and PI decrease and PL increase have observed in G soil with high plasticity clay (CH) content. Soil A also has shown a result similar to soil G. Soil A has occurred a decrease of approximately 4% in LL and an approximately 11.5% in PI. Cyrus et. al. (2010) and Ramya et al. (2018) reached similar results in their studies. They stated that as the salt concentration of clayey soils increased, LL and PI values decreased.

Mishra (2009) showed that LL decreased with increasing salt concentration. It can be stated that forces between particles play an important role in determining the liquid limit. The interaction forces between clay particles at the liquid limit equivalent to a fluid consistency can become weak enough to allow easy movement of the particles relative to each other. Especially, as the Na concentration increases in clays with high swelling properties, the bonds between particles may gradually weaken (Warkentin, 1961). This may cause a reduction in LL. Dolinar and Trauner (2004) stated that the LL value depends primarily on the type and amount of clay minerals in the soil.

LL, PL and PI values of K and Ş natural soils have shown an increase after wastewater leaked. The LL value of the Ş natural soil has increased by approximately 8.5% and the PI value by approximately 15.7% after the wastewater leaked. A very small increase has observed in the PL value. The PL value of K natural soil has shown more pronounced an increase compared to soil Ş. LL and PI values of K natural soil after infiltration has increased 10% and 16.5%, respectively. This increase in Atterberg limits can be explained by the chemical interaction between soil particles and wastewater. Irfan et. al. (2018) showed an increase in LL and PL of contaminated soils with wastewater. Karkush and Resol (2015) stated that soil samples contaminated with wastewater increased LL compared to uncontaminated soil. Jedari and Hamidi (2015) showed that the LL and PI values are respectively about 30% and up 10% as a result of the their study. They noted that the viscosity of pore fluids was effective in changing the index properties of contaminated soil. A contaminant with a denser viscosity compared to water can result in more water absorption.

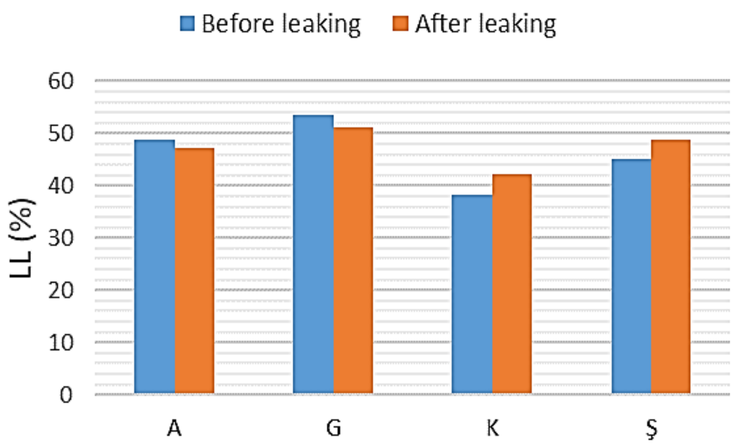


Figure 4.3 LL results of natural soils.

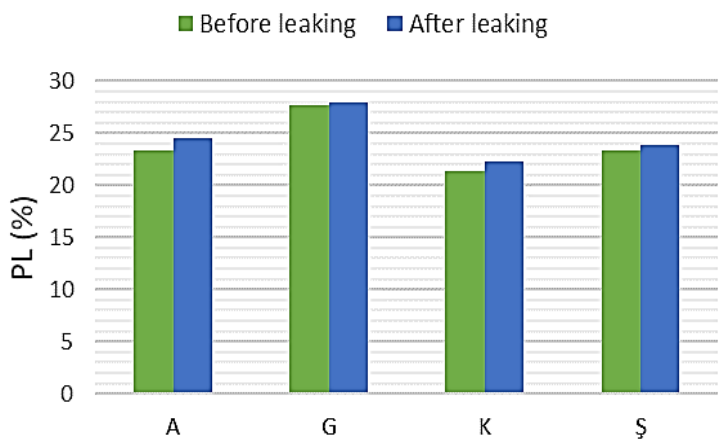


Figure 4.4 PL results of natural soils.

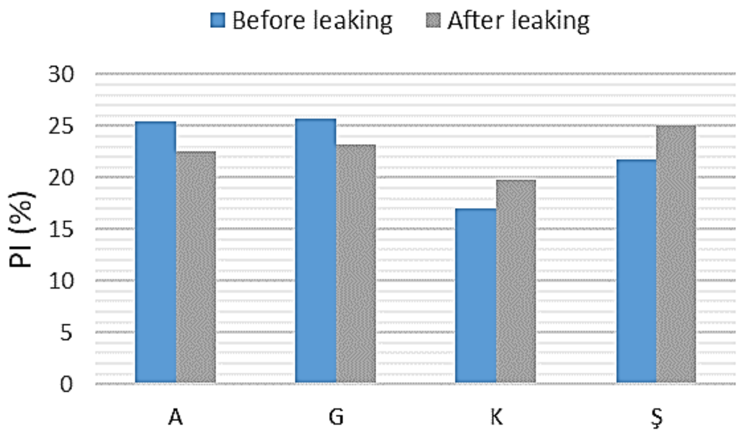


Figure 4.5 PI results of natural soils.

4.2.3 Specific Gravity (G_s)

Specific gravity can be defined as the ratio of the solid density of the soil to the density of water at 20°C. It is a dimensionless parameter. Specific gravity is used in geotechnical and geoenvironmental engineering in calculation of basic physical properties including void ratio, porosity, water content, degree of saturation and unit volume weight of soil (Yesiller et. al., 2014). Specific gravity results determined according to ASTM D854-14 standard are shown in Table 4.3.

Table 4.3 Specific gravity test results.

Specific Gravity	**A**	**G**	**K**	**Ş**
Before leaking	2.76	2.69	2.64	2.72
After leaking	2.74	2.68	2.67	2.69

The specific gravities of the A, G, K and Ş natural soils have found after and before the wastewater leaked. The specific gravity of A, G and Ş soils have decreased to a certain extent after the wastewater leaked, while the K soil has increased. Experimental results are consistent with literature studies. Khan et. al. (2017) observed that the specific gravity of CH soils decreased 1.4% and 2.3% with the increase in the contaminant concentration. They stated that the specific gravity of the CL soil is not much affected by contaminants. Irfan et. al. (2018) stated that the specific gravity of CH soils contaminated with wastewater decreased by 12% to 15% as a result of the 60 day experiment. They found that the specific gravity of the CL soil decreased at a higher rate. Sivapullaiah and Manju (2005) stated that the specific gravity of contaminated clayey soils generally decreased. Prakash and Arumairaj (2015) showed that the specific gravity of the clayey sample could decrease due to acidic contamination and could increase due to basic contamination.

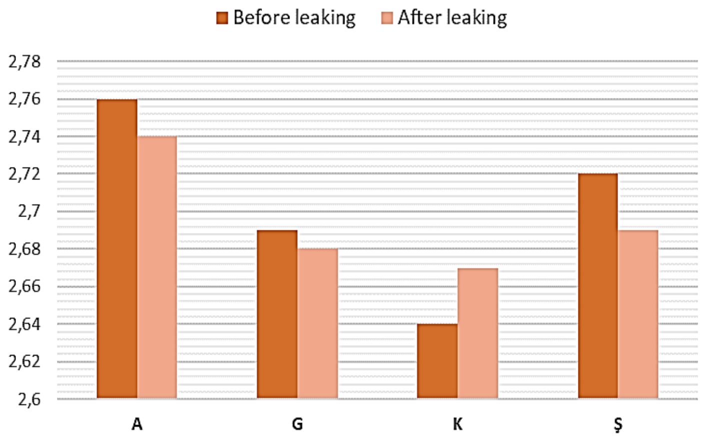


Figure 4.6 G_s results of natural soils.

4.2.4 Standart Compaction Test

Compaction characteristics of soil, i.e., optimum water content and maximum dry density are important engineering characteristic. The compaction properties of soils correlate well with its index properties (Sridharan and Nagaraj, 2005). Compaction properties of natural soils have determined in laboratory using the standard proctor test. Test results are shown in Table 4.4.

Table 4.4 Standard proctor test results.

Natural Soils	**A**		**G**		**K**		**Ş**	
	γ_{kmax} (ton/m^3)	ω_{opt} (%)	γ_{kmax} (ton/m^3)	ω_{opt} (%)	γ_{kmax} (ton/m^3)	ω_{opt} (%)	γ_{kmax} (ton/m^3)	ω_{opt} (%)
Before leaking	1.60	23.489	1.53	26.416	1.66	18.616	1.61	21.054
After leaking	1.61	21.302	1.56	23.500	1.63	19.900	1.60	21.500

Compaction parameters of soils have determined before and after wastewater leaked. When Table 4.4 is examined, it has seen that different results are reached for almost each soil. The maximum dry denstiy (γ_{kmax}) of soil G has increased after wastewater infiltration and the optimum water content (ω_{opt}) has decreased. The maximum dry denstiy has decreased partially and optimum water content has increased partially after the wastewater of the soil Ş is leaked. The maximum dry denstiy of soil A has partially increased and the optimum water content has decreased. Finally, the maximum dry denstiy of soil K has decreased and optimum water content has increased.

Results are compared with experimental data in the literature. Khan et. al. (2017) stated that wastewater pollution increased the optimum water content of the soil and decreased the maximum dry density (Oluremi et. al., 2012). Irfan et. al. (2018) noted that cohesive soils consistently reduced the maximum dry density with an increase in the pollutant percentage of wastewater. They stated that soil with a high concentration of pollutants would be difficult to compact and a lower unit weight could be obtained compared to uncontaminated soil under the same compaction effort and environment conditions. Jedari and Hamidi (2015) showed that the optimum water content decreased as a result of contamination of low and high plasticity clayey soils with organic liquids. They stated that contaminants with higher viscosity cause maximum dry density at low water content. Yalvaç (2011) showed that the optimum water content of the CH sample decreased and the maximum dry density increased in her study using different wastewater.

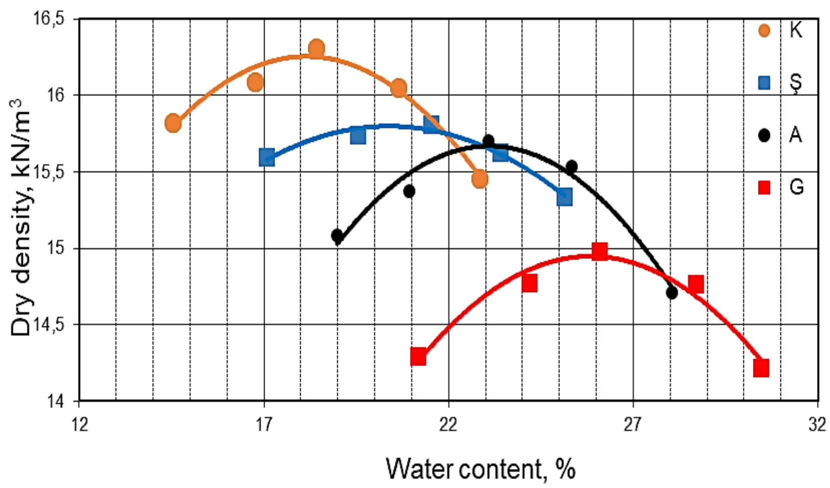


Figure 4.7 Compaction curves for natural soils.

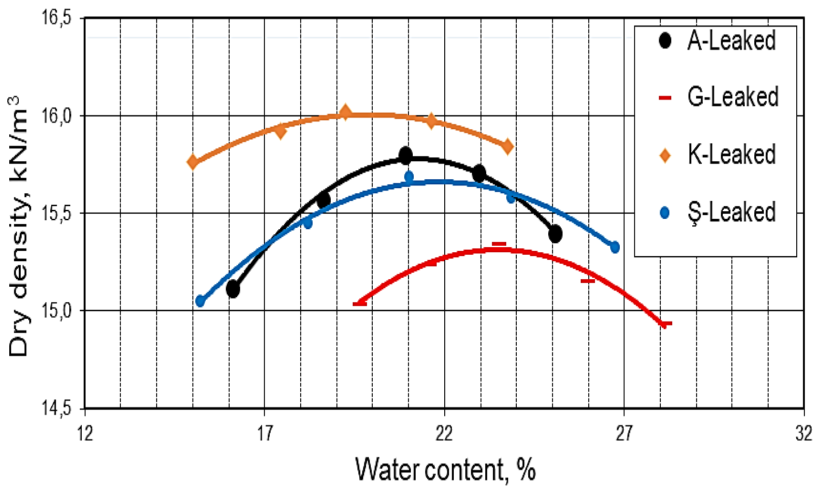


Figure 4.8 Compaction curves after wastewater leaked.

4.2.5 Unconfined Compressive Strength

Unconfined compressive strength (UCS) is a direct measure of strength for cohesive soils. A higher value indicates a better soil strength performance. Conversely, if the strength of the soil is low, the UCS value will also be low (Irfan et. al., 2018). The maximum axial compressive stress that natural soils can bear under unconfined conditions upon leaking wastewater are given in the Table 4.5.

Table 4.5 UCS test results.

Natural Soils	**A**		**G**		**K**		**Ş**	
	q_u (kPa)	ε (%)	q_u (kPa)	ε (%)	q_u (kPa)	ε (%)	q_u (kPa)	ε (%)
Before leaking	203.60	1.90	227.05	5.38	195.45	3.00	186.70	3.18
After leaking	192.6	2.09	216.80	4.95	183.58	2.50	175.70	2.77

When Table 4.5 is examined, it is observed that the unconfined compressive strength of the soils decreases after the wastewater leaks. Similar results have obtained for each soil. The strength of G soil has decreased by approximately 4.5% with the effect of wastewater. The strength of soils Ş and A decreased about 5.9% and that of soil K about 6.1% ratio. The decrease in strength due to wastewater effect can be refered attributed to possible weakening or breaking of soil particle bonds (Umesha et. al., 2012). In another way, the cementing effect that occurs in the soil helps fine grains bind together to form larger particle. The decomposition of the cemented particles in the soil due to the leakage effect may lead to a decrease in the unconfined compressive strength (Irfan et. al., 2018). In previous studies observed that similar results achieved. Oriola and Saminu (2012) determined the change of unconfined compressive strength (UCS) of soils treated with textile wastewater at 7, 14 and 28 days. The UCS of the soil first increased until 12% and then started to decline. Natural soil treated with textile wastewater reached peak UCS value in 7 days. Stalin et. al. (2010) shown that the unconfined compressive strength of soils decreases as the percentage of pollution in water increases in a study investigating the effect of tannery wastewater on two natural soils. This decrease in strength attributed to the viscosit of the pore fluidy and dielectric constant variables (Ratnaweera and Meegoda, 2006).

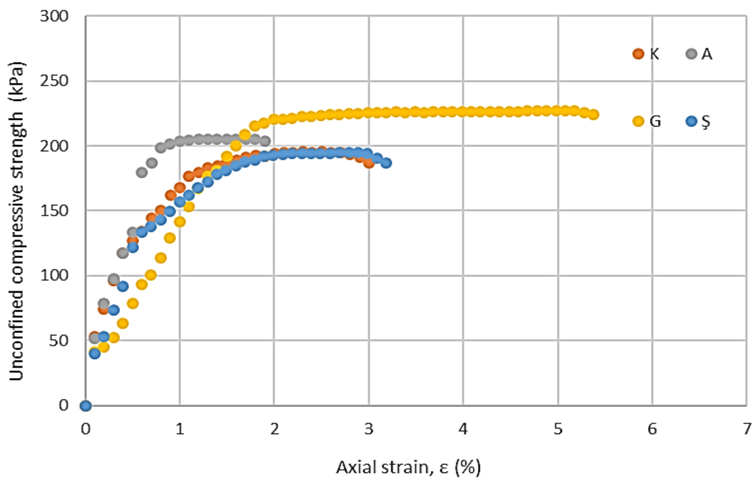


Figure 4.9 Stress-strain curves for natural soils.

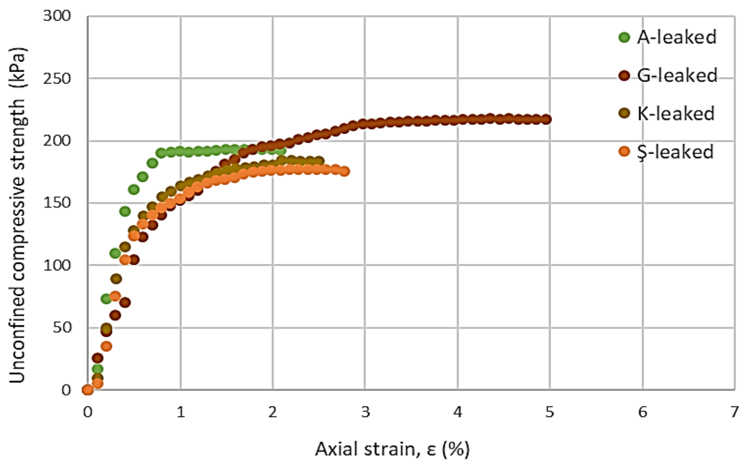


Figure 4.10 Stress-strain curves after wastewater leakage.

4.2.6 Falling Head Permeability Test

Definition of permeability of clays is required in many situations in geotechnical and civil engineering practice such as problems related to waste applications. It should be known that especially high plasticity clays are affected by pore fluid properties (Sridharan, 2014). The role of variables in environment conditions is important in influencing permeability (Sridharan, 1991). Permeability values of natural soils before and after wastewater filtration are shown in Table 4.6.

Table 4.6 Permeability values of natural soils.

Unit (cm/sn)	A	G	K	Ş
Before leaking	$9.16x10^{-9}$	$5.95x10^{-9}$	$9.64x10^{-9}$	$1.17x10^{-8}$
After leaking	$4.65x10^{-9}$	$7.00x10^{-9}$	$1.06x10^{-8}$	$1.36x10^{-8}$

Permeability test results are shown in Table 4.6. When the experimental results are examined, it is observed that the G, K and Ş soils exhibit a similar behavior. It has shown that soil A exhibits a different behavior. After wastewater leaks, it has found that the permeability of the G, K and Ş soils increased slightly and the permeability of A soil decreased.

Many studies have been conducted investigating the effects of organic and inorganic substances, namely the change in soil water chemistry on the permeability of clayey soil (Mitchell and Madsen, 1987; Reeve and Tamaddoni, 1965; Fernandez and Quigley, 1985; Ijimdiya, 2011; Madsen and Mitchell, 1989; Ramya et. al., 2018). Erarslan (2003) stated that the structure of clay may deteriorate by time in clayey soils contaminated with seepage water and this may lead to a decrease in the purification capacity of the water. In another study was observed adverse interactions that cause some shrinkage and cracking together with a large increase in hydraulic conductivity of clay soils which interact with pure organic liquids in almost all cases (Madsen and Mitchell, 1989). Pusch and Schomburg (1999) observed an before increase and then a decrease in the hydraulic conductivity of natural clay in their study. Karkush and Resol (2015) reported a decrease in the permeability of soils leaking industrial wastewater for 30 days. Meegoda and Rajapakse (1993) stated that there is no significant change in the short-term interaction of organic pollutants with clays, but that the permeability tends to increase in the long-term interaction.

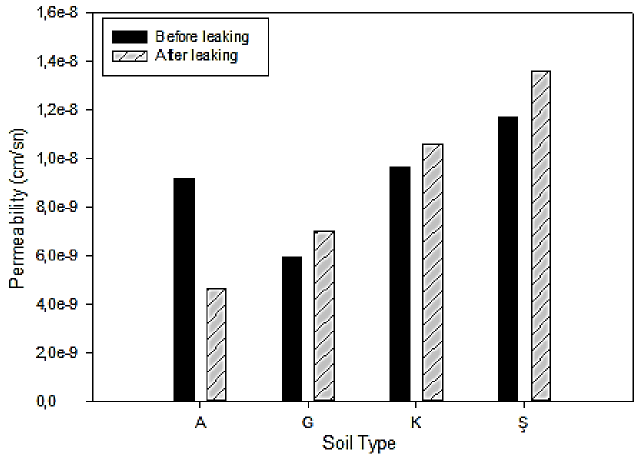
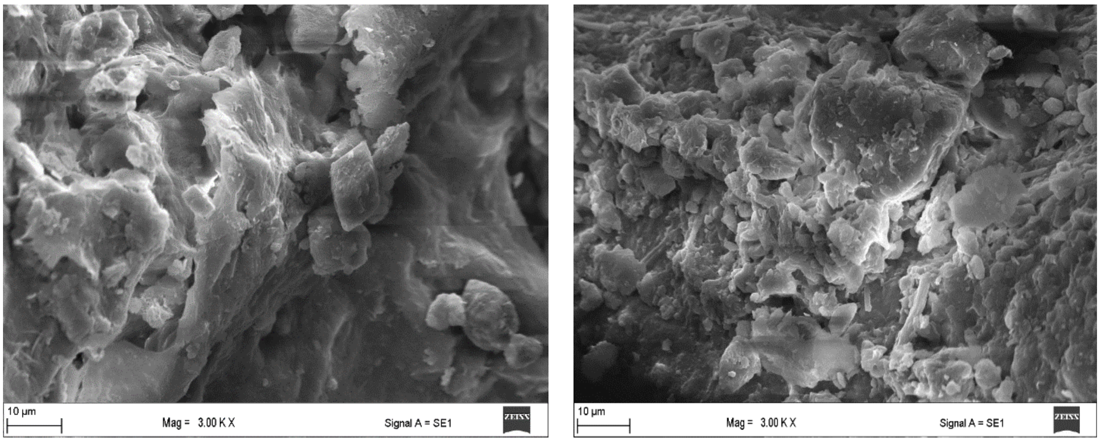


Figure 4.11 Permeability test results.

4.2.7 Scanning Electron Microscope (SEM)

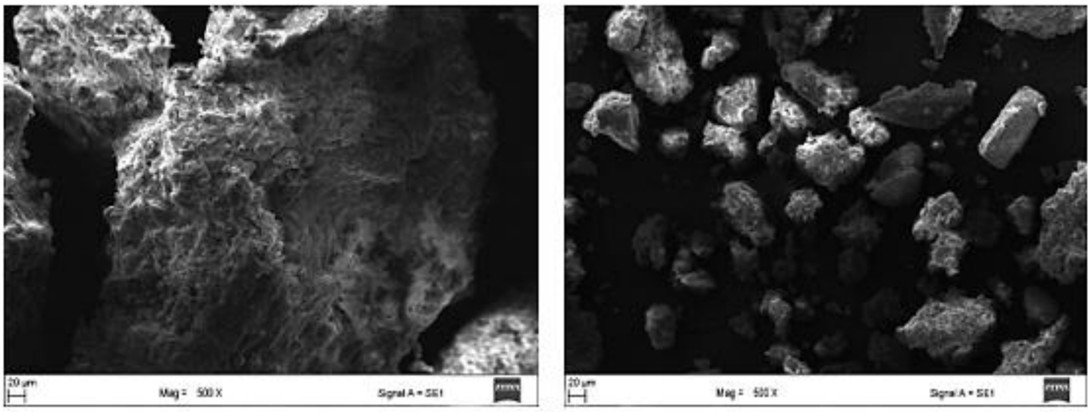
Scanning electron microscope (SEM) can be defined as an microscope that obtains images by scanning the sample surface. Therefore, SEM imaging was used to obtain information about the surface morphology and crystal structure of natural soil particles before and after wastewater infiltration. The following figures are given the imaging of natural soils at 20 µm diameter, 500x magnification and 10 µm diameter, 3.00KX magnification.

When SEM images are examined, different morphologies have observed depending on the magnification rates. It can be said that the distribution of particle sizes with the most distinctive appearance is not homogeneous. Before filtration, it can be stated that the soil particles are in a more compact form. Smaller sized pores may be formed as a result of dispersion or breakdown of soil particles after infiltration (Chen and Banin, 1975). This situation can be more pronounced at 20 µm diameter and 500X magnification. Another subject encountered in figures are that the particles are in different shades. Some particles look black, while some particles stands out in dark and light gray and whitish bright colors (Bulun, 2010). Previous studies showed with SEM observations that liquids with different concentrations could cause flocculation or dispersion in the microscopic structure of clays (Stawinski et. al., 1990; Chen and Banin, 1975).



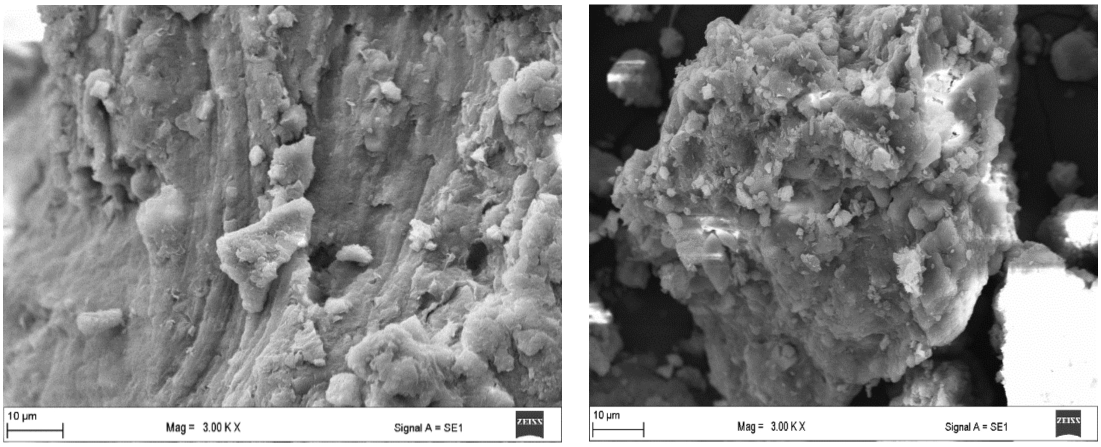
(1) Before leaking (2) After leaking

Figure 4.12 Sem image of A natural soil (10 µm, Mag:3.00KX).



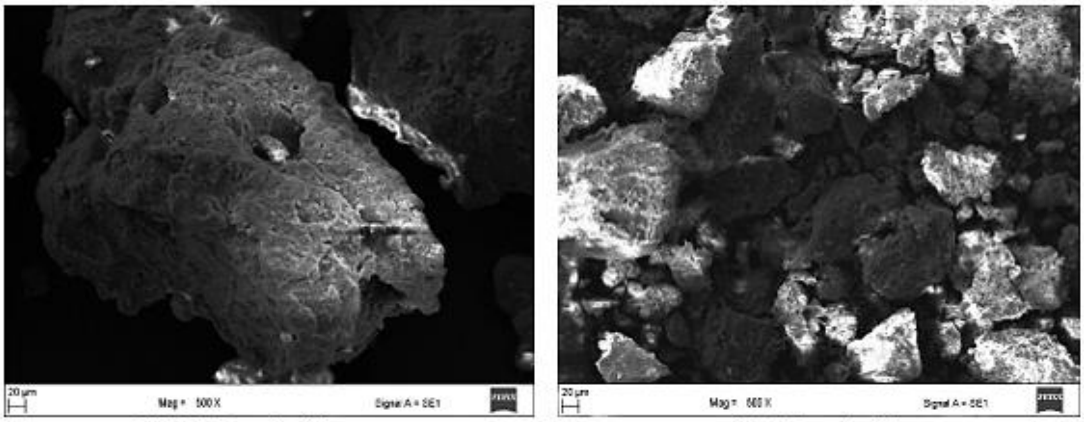
(1) Before leaking (2) After leaking

Figure 4.13 Sem image of A natural soil (20 µm, Mag:500X).



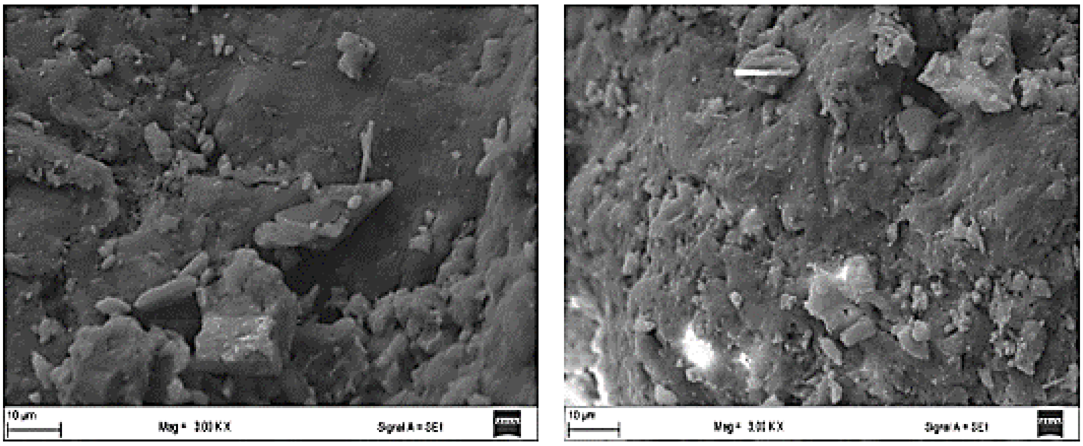
(1) Before leaking (2) After leaking

Figure 4.14 Sem image of G natural soil (10 µm, Mag:3.00KX).



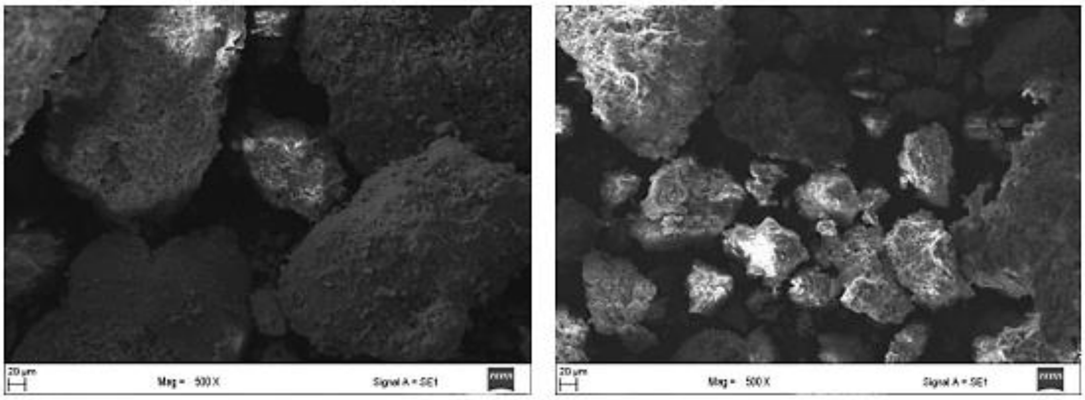
(1) Before leaking (2) After leaking

Figure 4.15 Sem image of G natural soil (20 µm, Mag:500X).



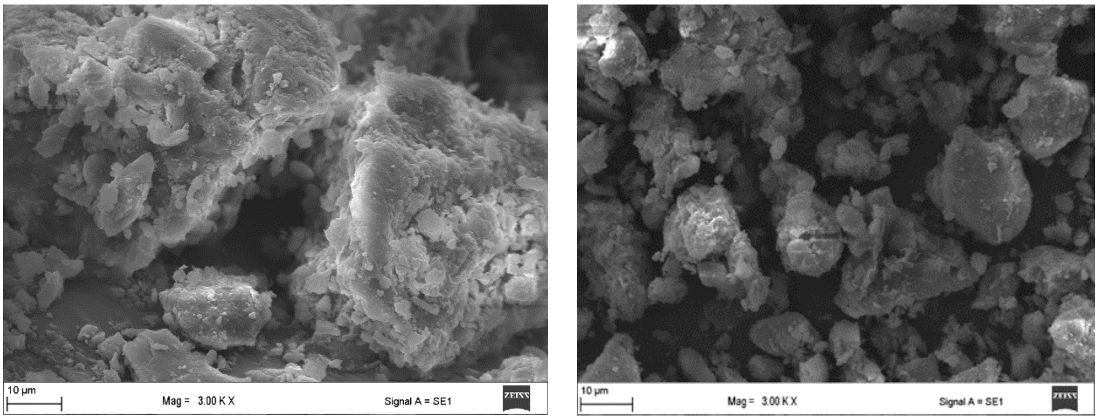
(1) Before leaking (2) After leaking

Figure 4.16 Sem image of K natural soil (10 µm, Mag:3.00KX).



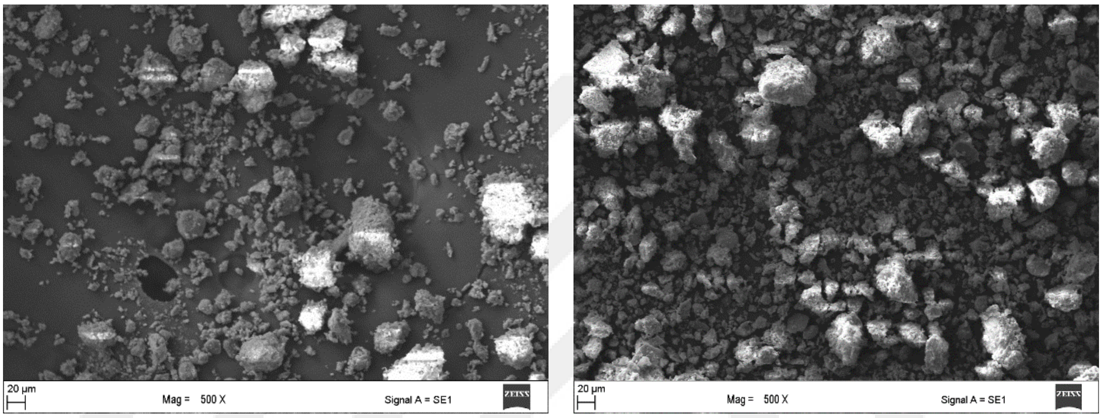
(1) Before leaking (2) After leaking

Figure 4.17 Sem image of K natural soil (20 µm, Mag:500X).



(1) Before leaking (2) After leaking

Figure 4.18 Sem image of Ş natural soil (10 µm, Mag:3.00KX).



(1) Before leaking (2) After leaking

Figure 4.19 Sem image of Ş natural soil (20 µm, Mag:500X).

4.2.8 Soil Elemental Analyses

Soil elemental analyses were carried out in order to determine the possible change of soil structure depending on the disposal of domestic wastewater. In particular, it was reported that increased concentration of sodium could reduce the stability of the soil and thus lead to a decrease in large-scale pore volume (Dawes and Goonetilleke, 2003; Hasan et. al., 2014). As a result of this situation, there could be a decrease in the hydraulic conductivity of the soil (Jnad et. al., 2001).

Salinity of the soil refers to the presence of easily soluble salts (mainly Na^{+}, Mg^{++}, Ca^{++}, K^{+}) in soil. These salts are associated with many physical and chemical properties of soil such as grain size and structure, bulk density, water content due to the affect of soil water retention (Murad, 2012). For this reason, the chemical properties of the soils collected from the columns before the wastewater was given and after the infiltration test were analyzed separately for each soil. Analysis results are given in Table 4.7, 4.8, 4.9 and 4.10. When the Table 4.7, 4.8, 4.9 and 4.10 are examined, nitrogen (N) has not been measured in the structure of natural soils Ş and K. Nitrogen is a condition related to the organic matter content of soils (Bremner, 1965). A very small amount of N has measured in the structure of soils G and A.

Depending on the elemental concentration of the control soil, the results of Na, Ca, Mg, P, K and SAR with higher concentrations have obtained as a result of some filtration processes. In previous studies, Na, Ca, Mg, K and SAR values with high concentrations in the soil were reached as a result of TWW irrigation processes (Hasan et. al., 2014; Klay et. al., 2010; Galavi et. al., 2010).

Table 4.7 Elemental analysis results of soil A.

Soil type	*Soil parameter*	*Before wastewater leaked*	*After wastewater leaked*	*Total change (%)*
A	Ca (mg/kg)	2192	1826	-16.70
	Mg (mg/kg)	171.1	142.6	-16.66
	Na (mg/kg)	3.261	7.319	+124.44
	K (mg/kg)	4.894	24.07	+391.83
	P (mg/kg)	359.6	74.21	-79.40
	N (%)	0.20879817	0.153939202	-26.30
	SAR	0.095	0.23	+142.10

Table 4.8 Elemental analysis results of soil G.

Soil type	*Soil parameter*	*Before wastewater leaked*	*After wastewater leaked*	*Total change (%)*
G	Ca (mg/kg)	2211	2689	+21.62
	Mg (mg/kg)	72.72	91.07	+25.23
	Na (mg/kg)	1.929	5.967	+209.33
	K (mg/kg)	13.00	24.03	+84.85
	P (mg/kg)	50.19	61.12	+21.78
	N (%)	0.16231136	0.160495475	-1.12
	SAR	0.057	0.16	+180.70

Table 4.9 Elemental analysis results of soil K.

Soil type	*Soil parameter*	*Before wastewater leaked*	*After wastewater leaked*	*Total change (%)*
K	Ca (mg/kg)	3119	2893	-7.25
	Mg (mg/kg)	97.59	100.8	+3.29
	Na (mg/kg)	2.194	4.664	+112.58
	K (mg/kg)	8.106	8.956	+10.49
	P (mg/kg)	97.83	88.34	-9.70
	N (%)	0	0	0
	SAR	0.055	0.12	+118.18

Table 4.10 Elemental analysis results of soil Ş.

Soil type	*Soil parameter*	*Before wastewater leaked*	*After wastewater leaked*	*Total change (%)*
Ş	Ca (mg/kg)	944.2	2441	+158.53
	Mg (mg/kg)	59.46	152.9	+157.15
	Na (mg/kg)	1.538	5.901	+283.68
	K (mg/kg)	9.548	29.37	+207.60
	P (mg/kg)	32.95	72.93	+121.34
	N (%)	0	0	0
	SAR	0.069	0.16	+131.88

Exchangeable cations Na, Mg, and Ca concentrations for calculation of SAR has been used (Suarez and Gonzalez-Rubio, 2017) . The SAR value is a good measure of the amount of exchangeable Na in the soil. The effects on infiltration of Na^+ which an important component of salinity have tried to be determined with the results of SAR.

When Table 4.7, 4.8, 4.9 and 4.10 are examined, there are an increase trend in SAR values as a result of filtration of natural soils. As a result of a similar study has determined that a result of which the SAR value of soil showed an increase compared to the control soil (Tahtouh et. al., 2019). This increase in SAR value can cause an increase in the salinity of the soil (Temizel and Tok, 2019). Läuchli and Epstein (1990) observed that excessive sodium rate of decrease soil permeability and infiltration rate due to decomposition and swelling of clays or breaking up of coarse grains. Jnad (2000) stated that the increase in Na concentration may lead to a decrease in soil pore size associated with a decrease in Ca concentration and consequently an increase in soil water retention. McIntyre (1979) stated that the physical properties of the soil may be adversely affected at a SAR value above 5. In another study, it was reported that a SAR value above 3 can significantly reduce the hydraulic conductivity of the soil (Patterson, 1997). Generally, it has been recommended that systems should be operated with water with lower SAR values in order to maintain the hydraulic conductivity of the soil in infiltration for a long time. Duan et. al. (2010) concluded that there was no significant change ($p < 0.05$) in the mean SAR value of the soil profile tested at the beginning and at the end of their study.

4.3 Experimental Results of Wastewater

In order to evaluate the discharge water quality of domestic wastewater leaked from 1 m natural soil columns to the receiving environment, comparisons were made with the values of the Ministry of Environment and Forestry, Water Pollution Control Regulation (e-Legislation no: 7221) discharge standards of domestic wastewater to the receiving environment (Changed:RG-13/2/2008-26786). The discharge standards contained in the regulation are given in Table 4.11.

Table 4.11 Discharge standard of wastewater in settlements where the population is between 84-2000 (e-Legislation no: 7221).

Parameter	**Unit**	**Composite Sample 2 hours**	**Composite Sample 24 hours**
Biochemical Oxygen Demand (BOD)	mg/L	50	45
Chemical Oxygen Demand (COD)	mg/L	180	120
Suspended Solids (SS)	mg/L	70	45
pH	-	6-9	6-9
***** At least 60% treatment efficiency will be applied for the discharge limits or parameters given in table for the villages.			

4.3.1 Chemical Oxygen Demand (COD)

The results of COD analyses are shown in the Figure 4.20, 4.21, 4.22 and 4.23. After the first and second sedimentation is completed, the influent water characteristics of the soil columns operating at different flow rates have shown changes significantly as a result of the filtration.

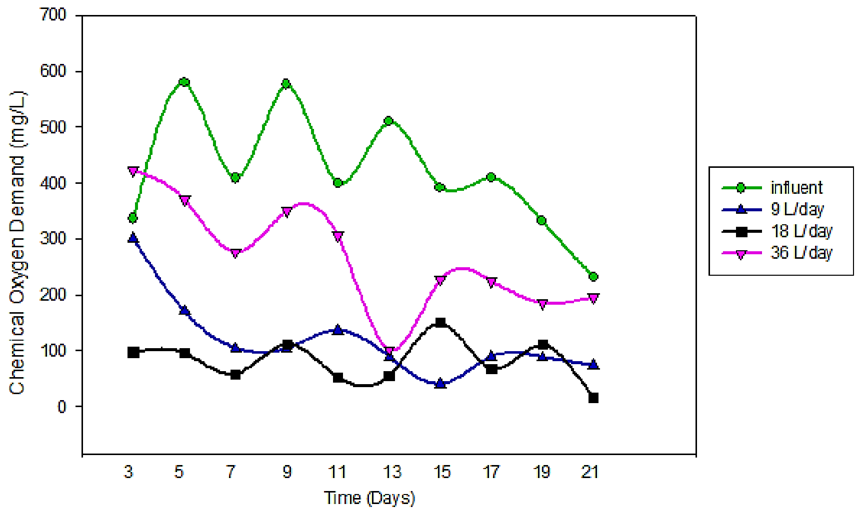


Figure 4.20 COD removal by filtration of A soil.

When Figure 4.20 is examined, it can be stated that the efficiency of the soil-column operating at high flow rate is lower compared to other flow rates. The maximum efficiency has achieved in the average effluent analysis of the soil-column operated at 18 day/L flow rate. COD concentrations in the effluent water have been found reduction in ratio 72%, 80.5% and 36% at flow rates of 9 L/day, 18 L/day and 36 L/day, respectively.

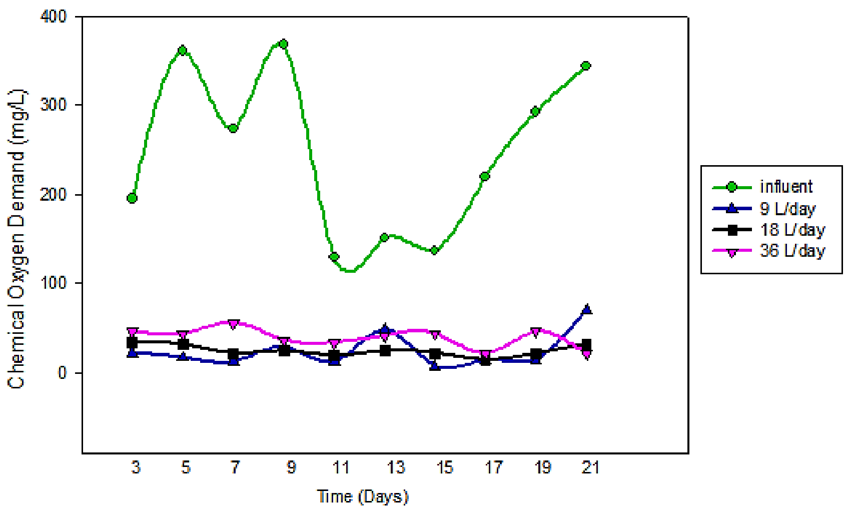


Figure 4.21 COD removal by filtration of G soil.

The influent water COD concentration of the soil column G is on average 247.15 ± 93.46 mg/L. When the efficiency in the columns operated at different flow rates has compared, the average COD values have found 24.89 ± 20.02 mg/L, 24.64 ± 6.14 mg/L and 39.28 ± 10.32 mg/L at flow rates of 9 L/day, 18 L/day and 36 L/day, respectively.

It has observed that the G soil column COD removal efficiency of domestic wastewater is approximately 90%.

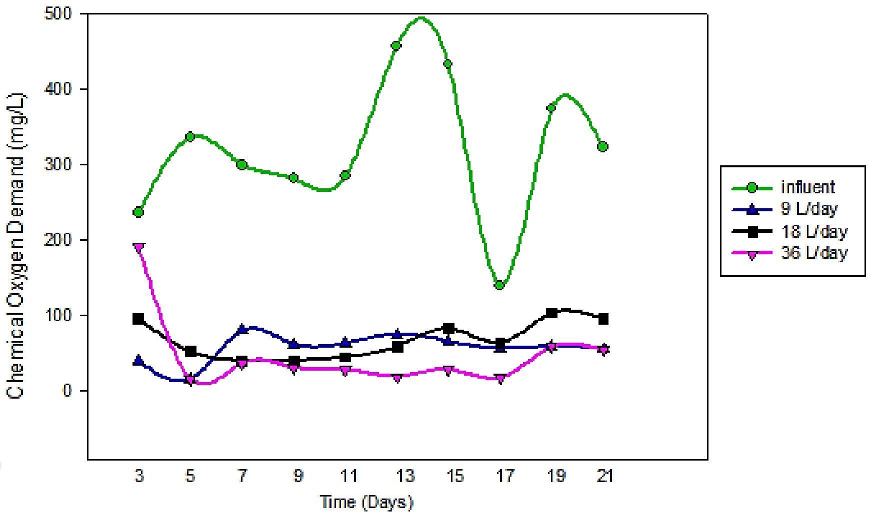


Figure 4.22 COD removal by filtration of K soil.

K soil column filtration results are given in Figure 4.22. The average influent water COD concentration has found as 316.18 ± 92.47 mg/L. The average filtration results have found as 57.40 ± 18.25 mg/L, 67.92 ± 24.83 mg/L and 48.32 ± 52.55 mg/L at flow rates of 9 L/day, 18 L/day and 36 L/day, respectively. It can be stated that the average COD removal in soil columns are between 78.5-85%.

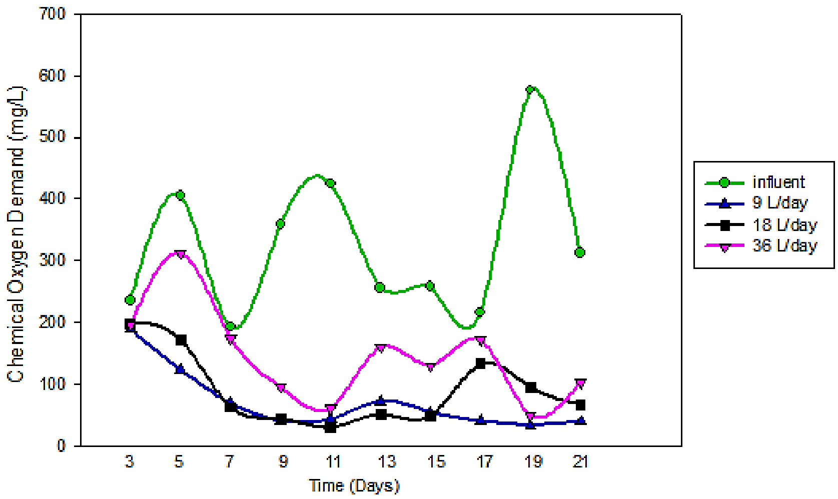


Figure 4.23 COD removal by filtration of Ş soil.

The influent water COD value of the soil column Ş is on average 323.14 ± 119.02 mg/L. The COD concentrations of the effluent water have found to average 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 are compared, it can be stated that the COD retention varies between 65-78.5%.

COD concentrations was in agreement with the findings of previous researches. Qin et. al. (2014) indicated that even though the efficiency of COD removal varies extensively, the lowest removal productivity was 60% and the average removal productivity exceeded 80%. Von Felde and Kunst (1997) concluded that COD removal can be eliminated over 90% in soil columns with vertical flow system (Zhang et. al., 2007). Hua et. al. (2003) stated that the COD removal efficiency varied range between 67%-79% for sewage water from dry and rain weather period. In another study was shown that COD could be kept at 86.7%-93.2% with a multi-layered artificial filtration area designed for rural domestic wastewater treatment (Lu et. al., 2015).

Soil filtration has reduced COD by removing organic particles or suspended solids. When the analysis results are examined, low COD concentrations have been obtained despite of frequently fluctuating influent COD. The receiving environment standards for the COD parameter is seen as 120-180 mg/L in Table 4.11. In terms of the COD parameter, it can be stated that the receiving environment standards can reach.

4.3.2 Conductivity

Conductivity is a parameter used in determining water quality. As the impurity in water increases, the conductivity of water increases. The conductivity values obtained as a result of wastewater analyses are given in Figure 4.24, 4.25, 4.26 and 4.27.

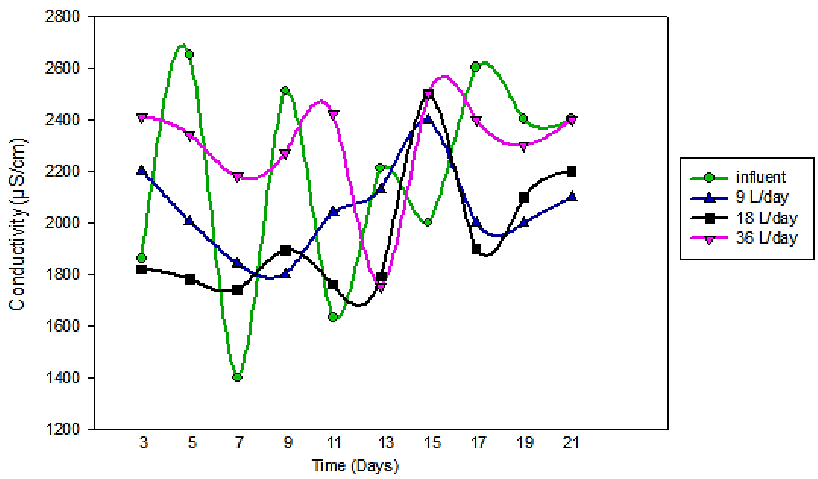


Figure 4.24 Conductivity of the A soil column filtration.

When the conductivity figures of the soil columns are examined, it is found that the average of the highest conductivity values is in the A soil column (Figure 4.24). At the same time, it can be stated that it is lower resolution graphic compared to other analysis results. The influent water conductivity average is found as 2166.10 ± 427.79 µS/cm. The average conductivity of the different flow rates varies between a minimum of 1948.20 ± 246.06 and a maximum of 2297.00 ± 212.34 µS/cm. There is no significant difference in average conductivity between influent and effluent water.

Conductivity of surface and wastewater generally depends on the total amount of dissolved solids (Franco et. al., 2017). Conductivity value can reach high values in polluted water or water where too much minerals from the soil are dissolved (Ucun Özel and Gemici, 2016). When Figure 4.24 is examined, it can be stated that the amount of solute in soil A may be higher.

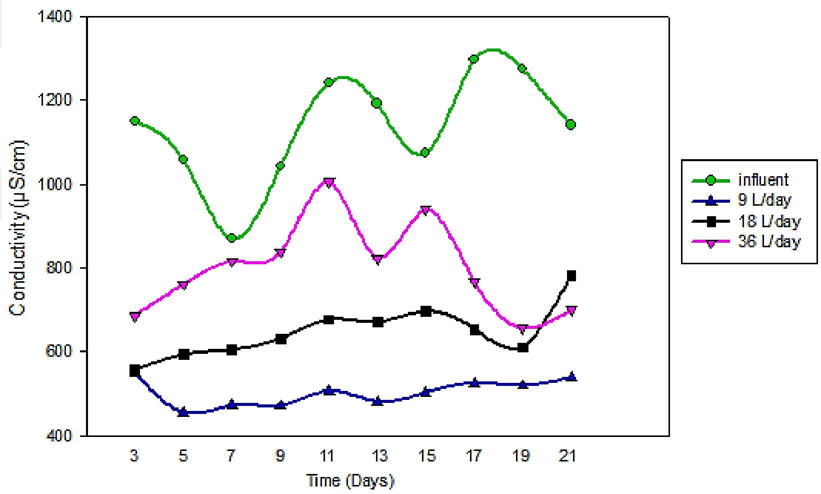


Figure 4.25 Conductivity of the G soil column filtration.

The average influent water conductivity for the G soil column is around 1133.00 ± 128.56 µS/cm. When Figure 4.25 is examined, it is seen that the minimum conductivity value is reached in the column fed with a flow rate of 9 L/day. When the effluent water average value of 9 L/day soil column is compared to the average value of column influent water, there has decreased of approximately 55.50%. Then, conductivity retention efficiency has realized in soil columns of 18 L/day and 36 L/day, respectively.

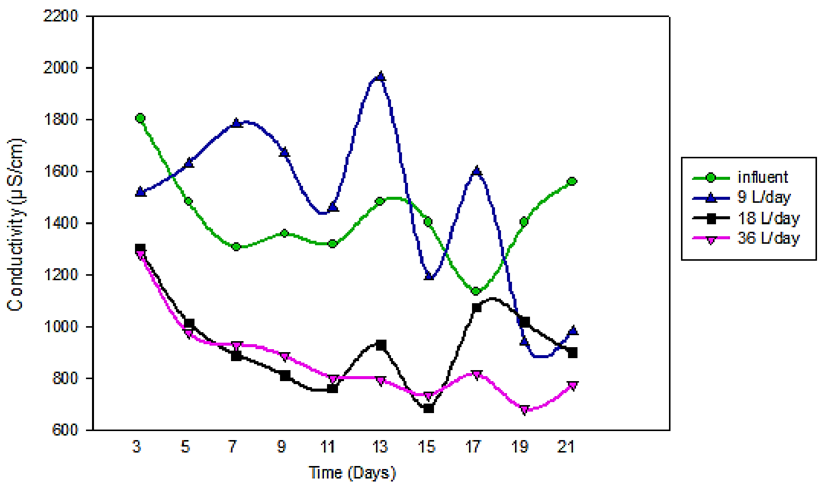


Figure 4.26 Conductivity of the K soil column filtration.

The flow rate of 36 L/day to the lowest medium in the soil column K has found to be 866.20 ± 169.84 µS/cm. Column influent water conductivity is on average 1423.60 ± 176.67 µS/cm.

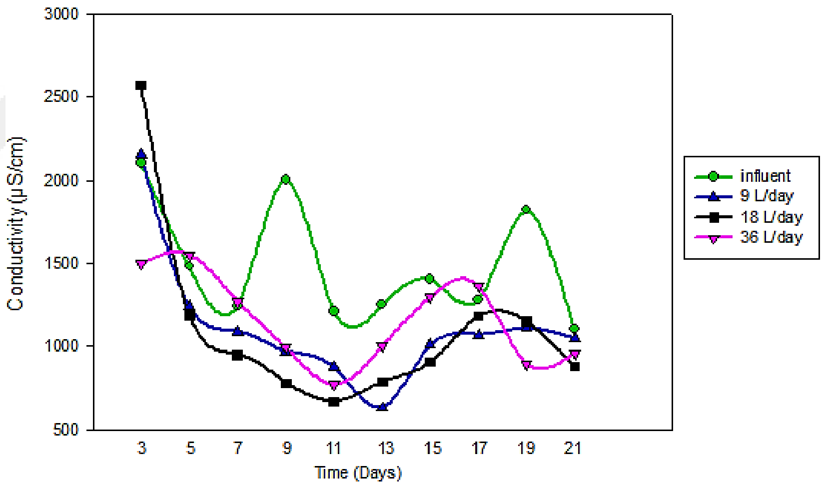


Figure 4.27 Conductivity of the Ş soil column filtration.

The average influent water conductivity value of the soil column is 1488.70 ± 337.71 µS/cm. It is observed that the average values of the soil columns operated at different flow rates are very close to each other. The average conductivity values have found to be 1119.40 ± 376.49 µS/cm, 1106.70 ± 517.01 µS/cm and 1160.00 ± 255.92 µS/cm at flow rates of 9 L/day, 18 L/day and 36 L/day, respectively.

Seasonal changes of conductivity values have been examined in some studies conducted. In these studies stated that the conductivity value of wastewater was higher in summer and lower in winter (Ucun Özel and Gemici, 2016; Igbinosa and Okoh, 2009; Okur et. al., 2001). Higher conductivity values measured in soil columns in summer are compatible with previous studies.

A good quality water should have a conductivity value below 400 µS/cm. Conductivity values have classified as that the range of 400-1000 µS/cm are classified as slightly polluted, between 1001-3000 µS/cm are polluted and water with a conductivity value above 3000 µS/cm are very polluted (e-Legislation no: 28483). When the results of the analyses are evaluated, it has shown that the effluent water of the soil column G are below 1000 µS/cm and the effluent water of the soil columns Ş and A are above 1000 µS/cm. Igbinosa and Okoh (2009) stated in their study that the conductivity measurements ranged from 225.53 to 490.80 µS/cm but this value was higher than the standards that could be discharged.

4.3.3 pH

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 of whether the water is acidic or basic.

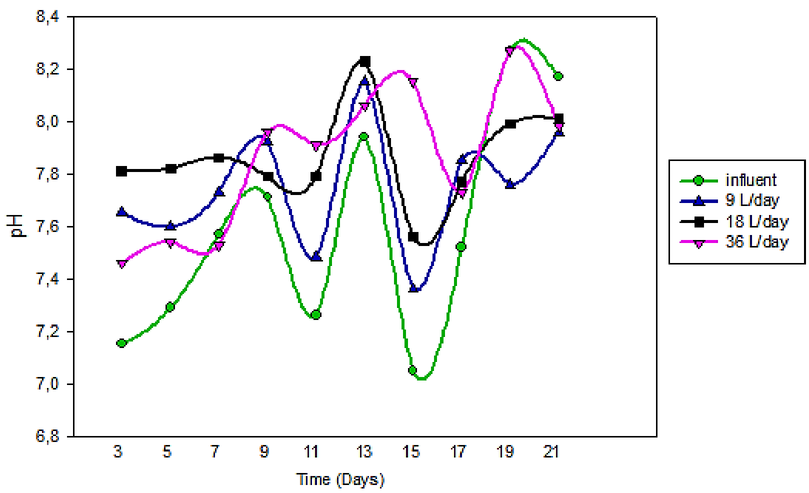


Figure 4.28 pH results of the A soil column.

When the A soil column analysis results are compared with other soil columns, the lowest average pH values are encountered. It has determined that the average effluents water are close to each other. Average influent water pH value has found to 7.59 ± 0.42 and average effluent water as 7.82.

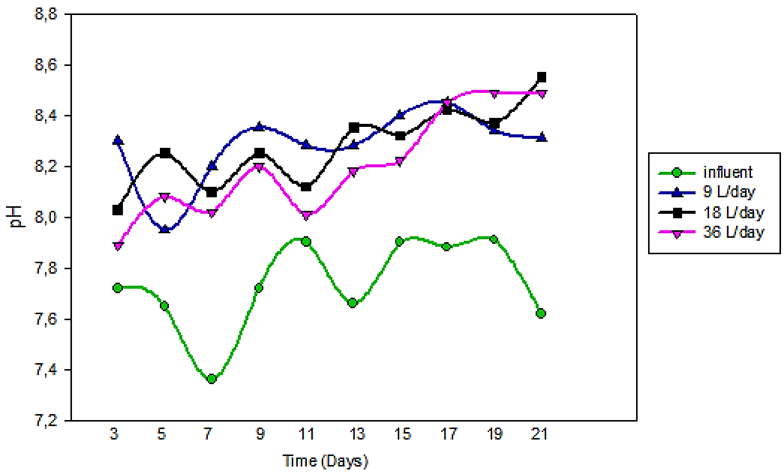


Figure 4.29 pH results of the G soil column.

G soil column influent water pH average has found as 7.73 ± 0.17. When the Figure 4.29 is examined, it are observed that the average pH values of the effluents increase as a result of filtration. This increase has continued to increase as the filtration time increased for each flow rate. It can be stated that the column effluent pH average values are 8.20 and above.

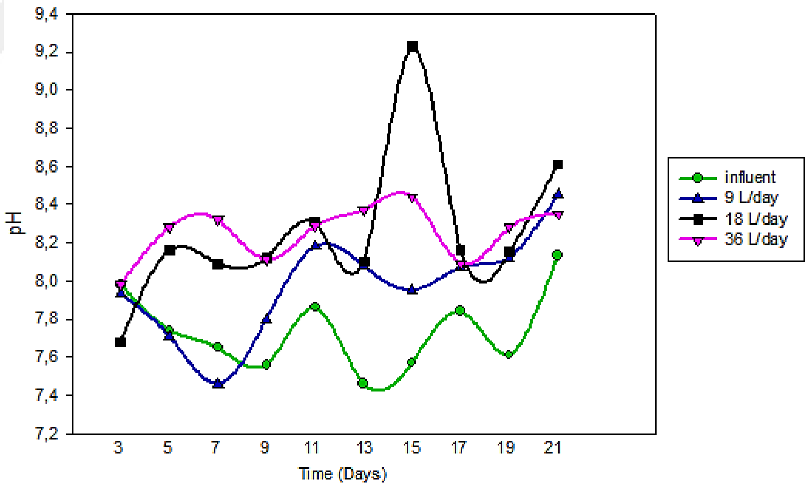


Figure 4.30 pH results of the K soil column.

K soil column filtration result is given in Figure 4.30. When the Figure 4.30 is examined, it is shown that the average effluent water of the soil columns fed with 18 L/day and 36 L/day flow rate are approximately 8.25. It has found that the average pH of the effluent water of the soil column operating at a flow rate of 9 L/day is higher than the average pH of the influent water.

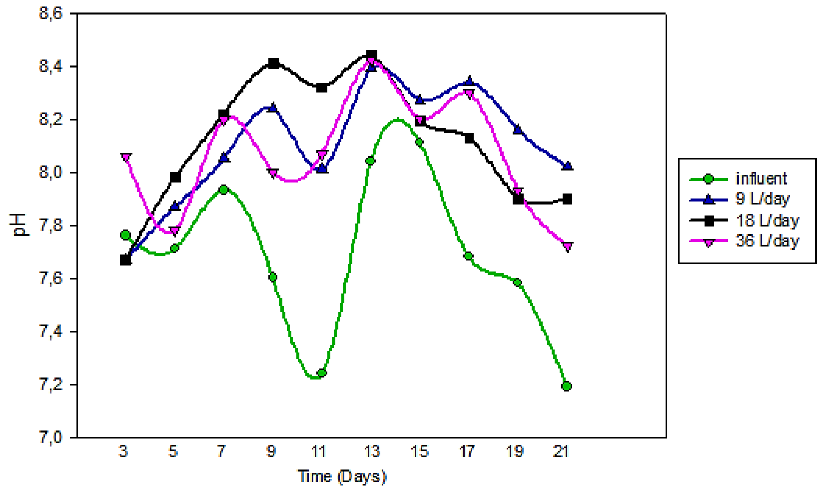


Figure 4.31 pH results of the Ş soil column.

When the Figure 4.31 is examined, it can be specified that the average of the pH value of the influent water is lower than the average of the pH value of the effluent water. It has found that the pH averages of the effluent of columns fed with different flow rates are almost similar.

According to the regulations of the TR Ministry of Forestry and Water Affairs, the pH of the wastewater is required to be between 6-9 before being discharged to the receiving environment (e-Legislation no: 28483). When the pH results are evaluated in general, it can be stated that the average pH value of each influent and effluent water is below the discharge limits. The influent water pH averages have found as 7.59 ± 0.42 in the minimum K soil column. The effluent water pH averages have found as 8.29 ± 0.14 in the maximum G soil column. Analysis results are similar to the study conducted by Suarez and Gonzalez-Rubio (2017). They determined that the original wastewater (influent) could be equivalent to or less than the treated wastewater. The pH values of the original and treated wastewater were measured in the range of 7-8.

4.3.4 Suspended Solids (SS)

The high amount of SS in water sample is a parameter that negatively affects the effluent water quality and the receiving environment. It can cause precipitations and cloggings in filtration (Rodgers et. al., 2004). The SAR can be stated as a simple parameter by which salt-affected soils can be determined when swelling clays are present (Bourrie, 2014).

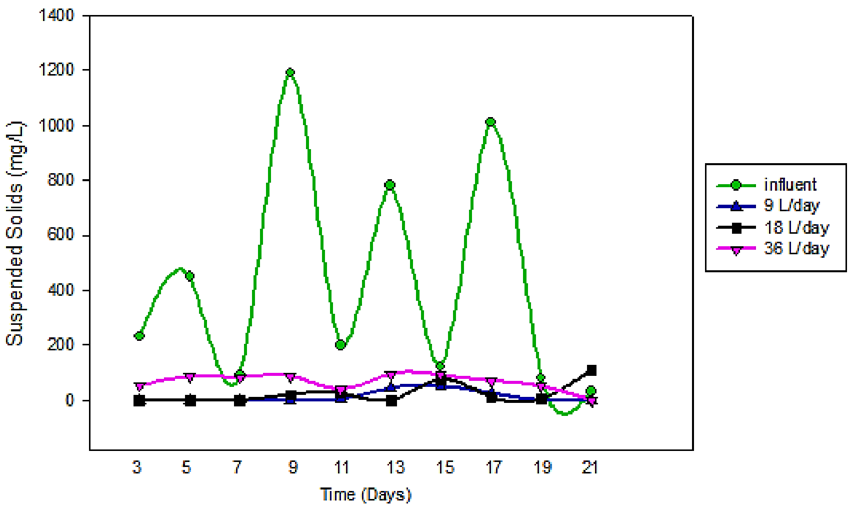


Figure 4.32 A soil column SS concentration.

The A soil column has the highest concentration of influent water SS (average 418.00 ± 424.60 mg/L) compared to other soil colums. The SS retention efficiency has decreased as the flow rate increased. The maximum efficiency rate of soil columns has found to be 97% and the minimum efficiency rate is 84.5%.

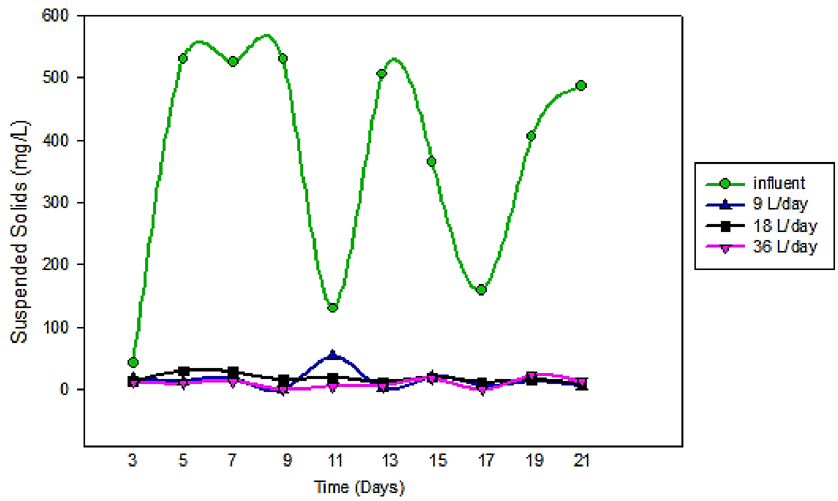


Figure 4.33 G soil column SS concentration.

When Figure 4.33 is examined, the average influent water SS concentration has found to be around 367.89 ± 187.96 mg/L. The variation in SS concentration has resulted close for all three flow rates. Compared to the influent, the SS is retained by the soil columns at about 96.50%.

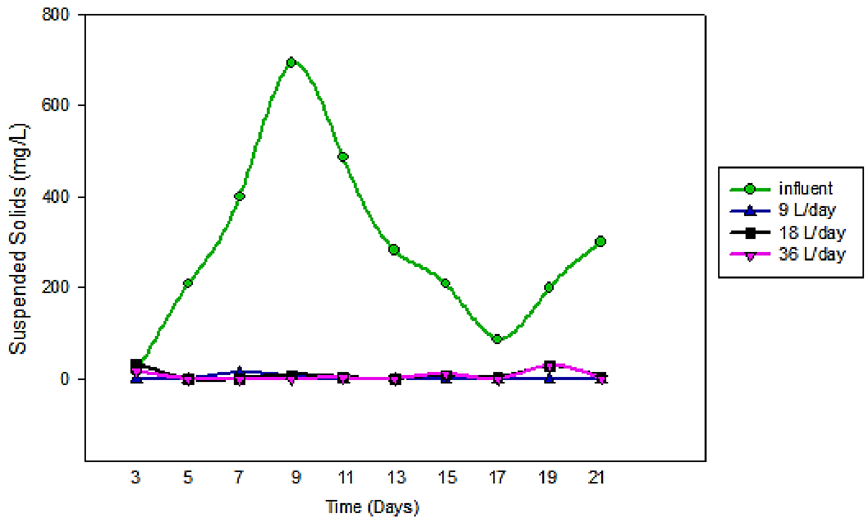


Figure 4.34 K soil column SS concentration.

The results of the K soil columns are given in Figure 4.34. The K soil column influent water SS concentration has the lowest average compared to other soil columns. It can be stated that the K soil column has reached a steady state since the day it started to operate. The average SS concentration of the effluent water of the soil column fed with a flow rate of 9 L/day is 2.03 ± 4.49 mg/L. This value has found as the minimum concentration of SS reached as a result of different soil filtrations.

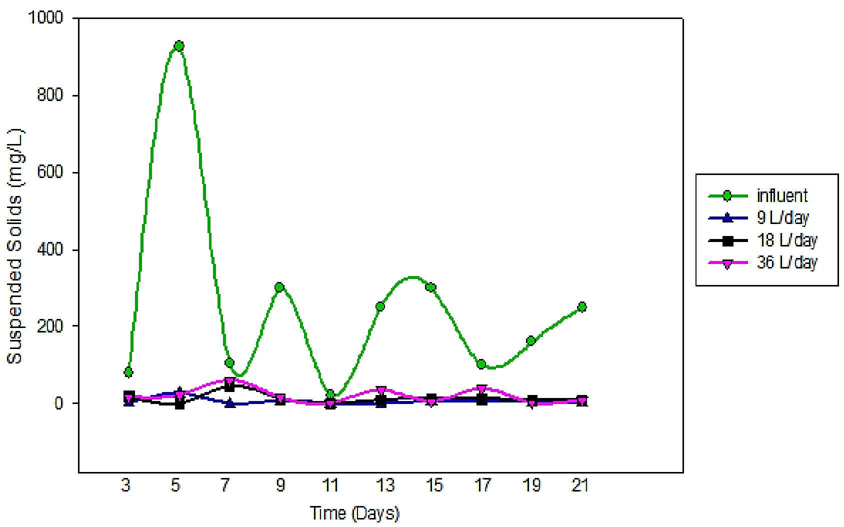


Figure 4.35 Ş soil column SS concentration.

SS concentrations of Ş soil column effluent water have found to be 5.01 ± 7.90 mg/L, 12.82 ± 12.75 mg/L and 20.60 ± 18.79 mg/L at flow rates 9 L/day, 18 L/day and 36 L/day, respectively. These values have retained at 98%, 95% and 92% efficiency, respectively, compared to the soil column influent water SS concentration.

When SS analysis results are examined, it is shown that similar results are obtained for all four natural soils. It is shown that the SS concentration results are below the wastewater discharge standards values given in Table 4.11. In addition, the experimental results are compatible with other studies in the literature. Murugaiyan and Saravanane (2009) found SS concentrations between 6.50 and 8.30 mg/L by day 3 in three natural soil column filtration.

Chun et. al. (2008) found that the influent water SS concentration of the system was 184 mg/L, while the effluent water SS concentration was 6-17 mg/L. They stated that the SS removal efficiency of the soil filtration system was between 91% and 97%. SS was almost completely removed in a study where microfiltration was used in treatment of domestic wastewater. A removal efficiency of over 99% was achieved in effluent water quality (Ahn and Song, 1999). Barrett (2003) stated that various filter configurations containing coarse media such as sand and gravel are 90% or more effective in holding suspended solids. Todt et. al. (2014) reached a total suspended solids decrease of 60–70% for blackwater treatment and 80–90% for domestic wastewater treatment.

4.3.5 Hardness

Hardness can be defined as a measure of calcium and magnesium dissolved in water (Dudziak and Kudlek, 2019). Generally, water containing calcium carbonate below 75 mg/L are considered as soft. Medium hard, hard and very hard water are classified as 75-150, 150-300, 300 mg/L and above, respectively. In this study, hardness was calculated depending on the concentration of calcium and magnesium (Samsunlu, 2011). The hardness levels of natural soil filtration have calculated as a result of ICP-OES elemental analyses.

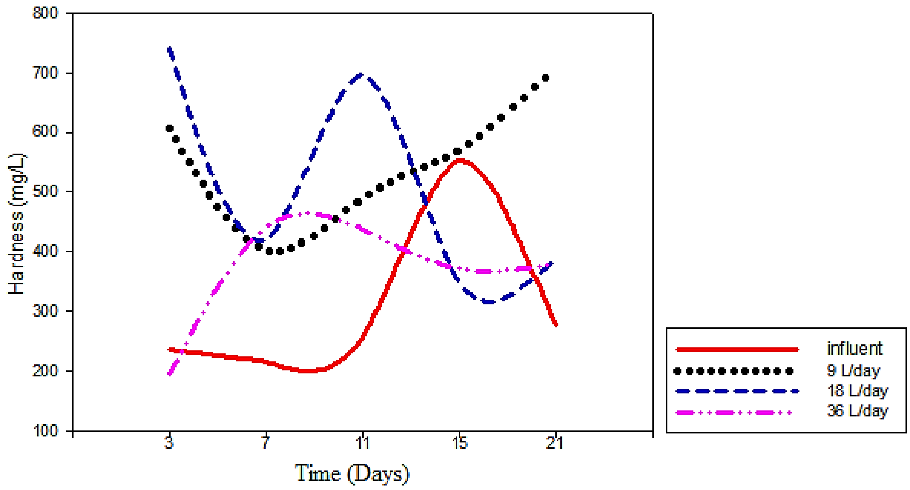


Figure 4.36 Hardness results of A soil column.

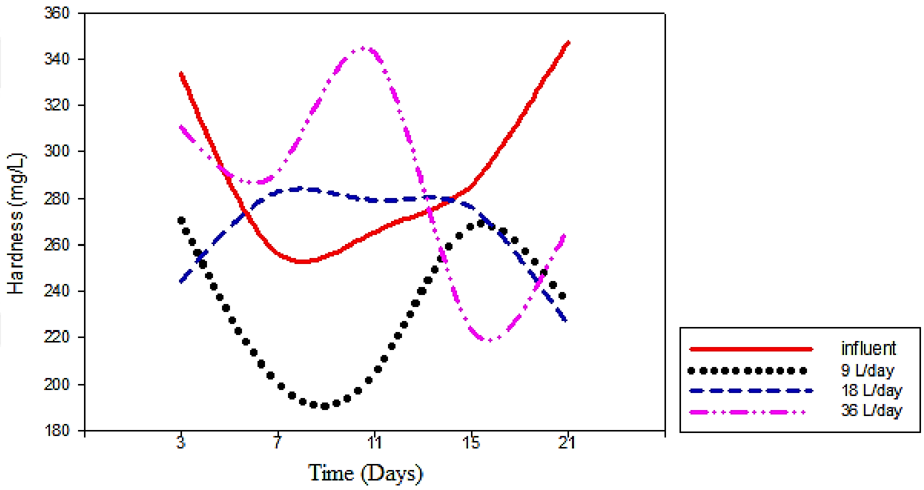


Figure 4.37 Hardness results of G soil column.

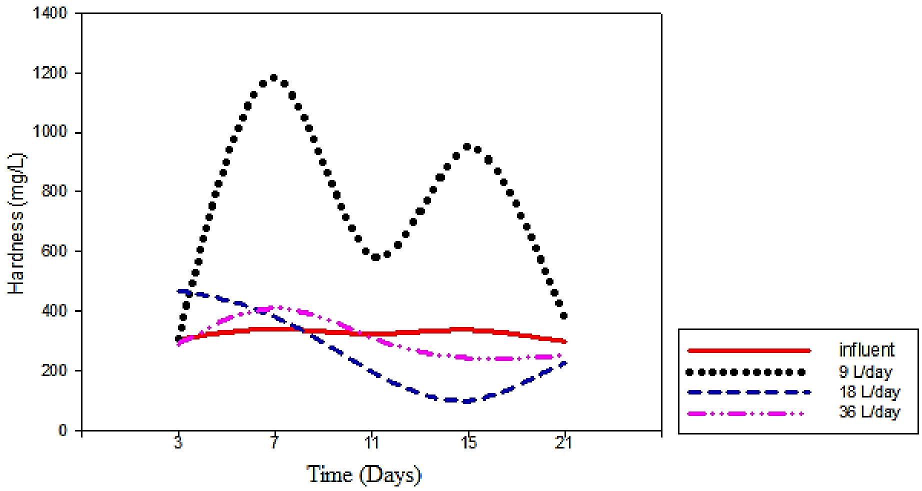


Figure 4.38 Hardness results of K soil column.

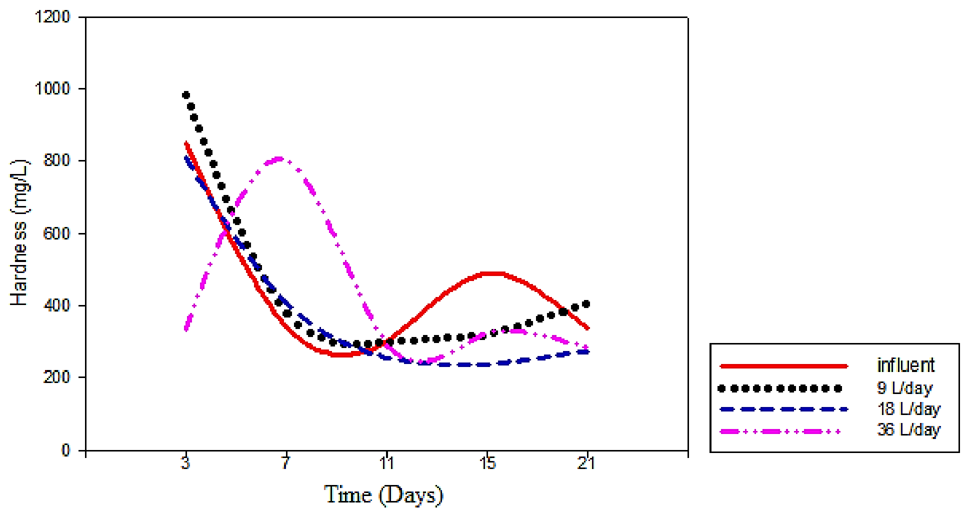


Figure 4.39 Hardness results of Ş soil column.

The A soil column average degree of hardness of the influent water is lower compared to the effluent water. The soil column with the lowest average effluent water hardness level has found to be fed with 36 L/day flow rate. The highest one is the soil column fed with 9 L/day flow rate.

When the Figure 4.37 is examined, the average influent water hardness in the G soil column has determined as 297.67 ± 41.01 mg/L. The minimum hardness level of the soil column operating with a flow rate of 9 L/day has found to be 200.33 and the maximum hardness level as 270.83. The soil column operated with a flow rate of 18L/day, it is minimum 225.87 and maximum 282.90mg/L. At the other flow rate, it has found to be a minimum of 223.19 and a maximum of 343.13 mg/L.

According to the Figure 4.38 results, the degree of average hardness the influent water is 320.80 ± 18.33 mg/L. The averages of the effluent water hardness have calculated as 681.86 ± 376.88 mg/L, 274.2 ± 148.82 mg/L and 300.30 ± 66.85 mg/L at flow rate of 9 L/day, 18 L/day and 36 L/day, respectively.

The average of Ş soil column influent water hardness has calculated as 464.60 ± 227.86 mg/L. Column effluent water hardness averages have varied between 396.88-478.08 mg/L.

As a result, the average of the highest hardness degree of the influent water of the soil columns have found as 464.60 ± 227.86 mg/L. The average effluent water hardness degree as a result of soil filtration has found to be the highest 681.86 mg/L and the lowest 235.73 mg/L. The influent water hardness of the soil columns can be classified as 'very hard' on average and the hardness level of the effluent water as 'very hard' and 'hard' on average (Samsunlu, 2011). Khanbilvardi1 and Long (1985) observed that the limestone based soil environment caused the hardness of the wastewater to increase after it was completely wetted. This observation confirmed with increasing limestone soil depth by soil columns. Substances that can be easily dissolved or decomposed in the soil structure can effects the hardness of wastewater (Tölgyessy, 1993). In another study observed that there was an increase in the calcium value and so an increase in the hardness of water in the first 15 cm of soil columns. Column effluent water hardness varied between 400 and 600 mg/L in study (Zhang and Shan, 1999). Abiye et. al. (2009) exhibited a decreasing in total hardness in order of 28 and 42% respectively in soil column laboratory exercise.

4.3.6 Sodium Adsorption Ratio

The SAR is a measure of the suitableness of irrigation water that can be determined by means of the concentrations of dissolved solids in water. If irrigation water consists of high SAR the sodium in water can change the magnesium and calcium in soil. This can cause decrease the infiltration and permeability of the soil (Sivakumar et. al., 2015). The sodium hazard classes based on SAR according to The United States Salinity Laboratory Staff diagram (USSLS) classification for groundwater is presented in Table 4.12 (Richards, 1954; Sivakumar et. al., 2015; El-Sayed and Salem, 2015). This classification about SAR is primarily based on the effect of exchangeable sodium on the physical condition of the soil (Cemek and Oktaş, 2020). The average SAR values obtained from the soil column filtration as a result of the experimental study are given in the Table 4.13.

Table 4.12 Rating of water samples in relation to 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 4.13 Classification of the influent and effluent water of soil columns in terms of SAR.

Soil Type	*Sample*	*SAR (mg/L)*	*Remark on quality*
A soil 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*
G soil column	Influent	7.38 ± 2.92	*Low or no hazard*
	9 L/day effluent	0.09 ± 0.20	*Low or no hazard*
	18 L/day effluent	1.35 ± 1.32	*Low or no hazard*
	36 L/day effluent	3.39 ± 1.26	*Low or no hazard*
K soil column	Influent	10.90 ± 3.6	*Medium hazard - Appreciable*
	9 L/day effluent	5.70 ± 7.12	*Low or no hazard*
	18 L/day effluent	6.98 ± 4.42	*Low or no hazard*
	36 L/day effluent	3.65 ± 1.37	*Low or no hazard*
Ş soil 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*

The wastewater samples examined for soil columns influent water are included the medium and low sodium hazard classification based on the USSLS classification. Class S2 water can be used for coarse textured soils with good permeability. The effluent collected from soil columns as a result of filtration of wastewater are classified as S1-Low or no hazard for G, Ş and K soil columns. The average effluent water of the columns fed with 9 L/day and 36 L/day flow rate in the A soil column is classified as high hazard. The interaction of the A soil column and water associated with the highly exchangeable sodium content may have formed an unstable structure (Wang, 2016). In such filtration areas may be required special soil management, good permeability, good drainage and adding organic matter. In addition, gypsiferous soils may prevent the development of harmful altered sodium in interaction with such water (Richards, 1954; Saghebian et. al., 2014; El-Sayed and Salem, 2015). In this respect, it can benefit filtration areas. Most samples of treated wastewater in this study have shown a low or harmless level of sodium, which is not a danger of sodium and water that can be used in terms of sodium. Alobaidy et. al. (2010) found similar results in their studies. As a result of the study, it was stated that soil salinity should be controlled and more studies were needed on the change of chemical elements in water and soil.

Time dependent changes of the SAR values at different flow rates are shown in Figure 4.40, 4.41, 4.42 and 4.43.

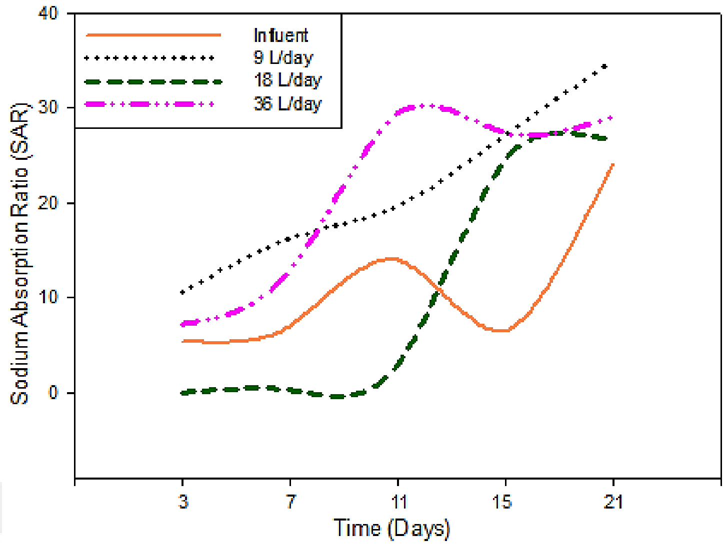


Figure 4.40 SAR results of A soil column.

When the Figure 4.40 is examined, the average SAR of water influent the A soil column has calculated as 11.37 ± 7.85. It has observed that the average effluent water SAR average of the soil columns fed with a flow of 9 L/day and 36 L/day increased almost 2 times compared to the influent water. The average SAR value of the effluent water of the soil column fed with 18 L/day flow rate has found to be close to the influent water. When Figure 4.40 is examined, as the filtration time in the soil column increases, the SAR has increased gradually.

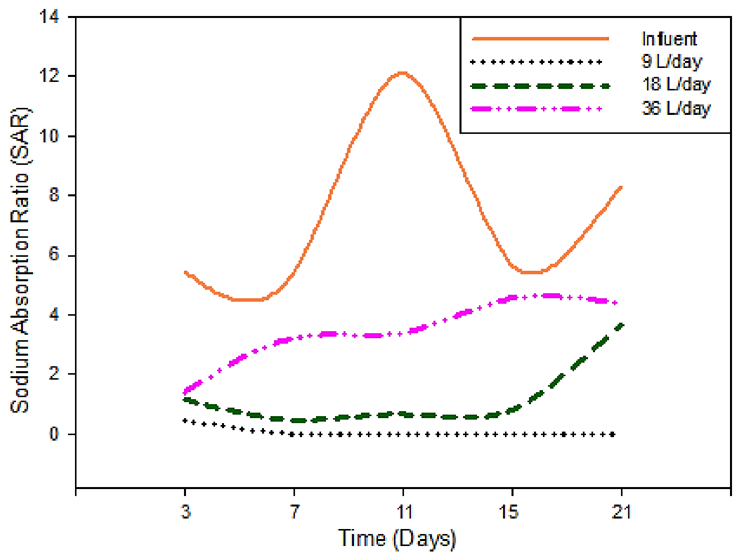


Figure 4.41 SAR results of G soil column.

The G soil column result have shown a more stable trend than other soil columns. When the Figure 4.41 is examined, the highest SAR value has calculated as the average influent water. Then, 36 L/day, 18 L/day and 9 L/day soil filtration effluents have calculated respectively. Average SAR in the soil column fed with 9 L/day flow rate has found approximately 0.

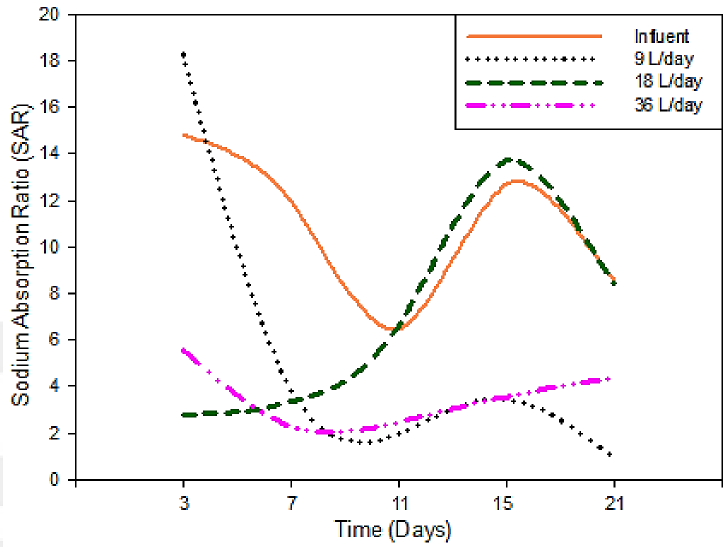


Figure 4.42 SAR results of K soil column.

The average influent water SAR value of K soil column has found to be 10.90 ± 3.36. This value in the effluent water of the soil columns fed with 9 L/day, 18 L/day and 36 L/day flow rate has retained at the rate of 47.70%, 36% and 66.50%, respectively.

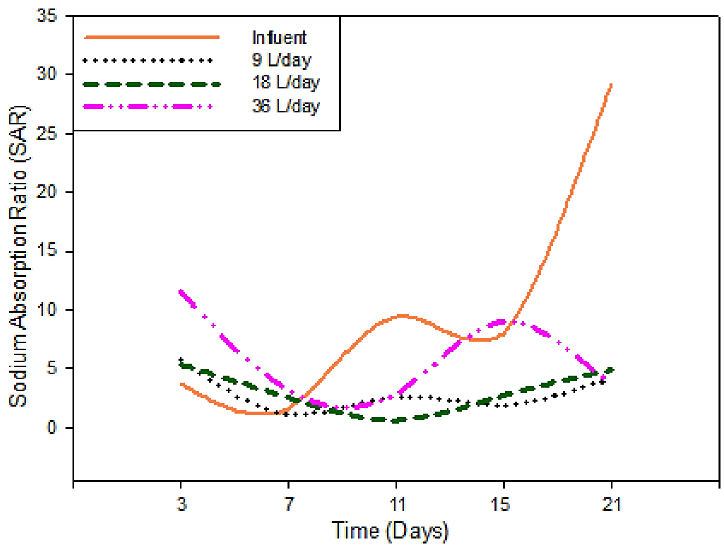


Figure 4.43 SAR results of Ş soil column.

The results of the soil column SAR are given in the Figure 4.43. The soil column influent water SAR average has calculated as 10.37 ± 10.94. This value has decreased to 3.10 ± 1.83 in average effluent water of the soil column fed with 9 L/day flow rate. The SAR in the soil column fed with 36 L/day flow rate has retained at approximately 41% and the average effluent SAR value has found to be 6.06 ± 3.98.

SAR values in the influent and effluent water of soil columns can be explained by the relationship between calcium, magnesium and sodium cations between clay or soil (Bedbabis et. al., 2014). These ions can be absorbed by the soil as a result of the reaction of soluble salts with clay (Sarah, 2004). In another way, it has been observed that 8%-26% of the soluble Ca^{2+} and Mg^{2+} in wastewater can bind to organic molecules and as a result, the effective SAR value of the water can increase (Metzger et. al., 1983). This situation has been shown to contribute to the reduction of hydraulic conductivity in soils where wastewater is applied (Pistol, 1981). Generally, the increase in SAR in soils irrigated with improved wastewater is associated with water infiltration rate which adversely affects filtration (Bedbabis et. al., 2014; Lado and Ben-Hur, 2009).

4.3.7 Total Phosphorus (TP)

Phosphorus is one of the important parameters in the discharge of treated wastewater. The average results of phosphorus obtained as a result of wastewater filtration are given in the Table 4.14.

Table 4.14 The average TP analysis results of soil columns (mg/L).

Soil Type	Influent	9 L/day	18 L/day	36 L/day
A soil-column	4.45 ± 2.01	1.03 ± 1.01	1.99 ± 1.90	3.34 ± 0.81
G soil-column	4.42 ± 1.38	0.64 ± 0.96	1.08 ± 0.74	0.15 ± 0.22
K soil-column	4.44 ± 1.46	1.12 ± 1.50	0.99 ± 0.70	0.66 ± 0.76
Ş soil-column	4.19 ± 0.70	1.12 ± 0.34	1.43 ± 1.17	3.19 ± 1.25

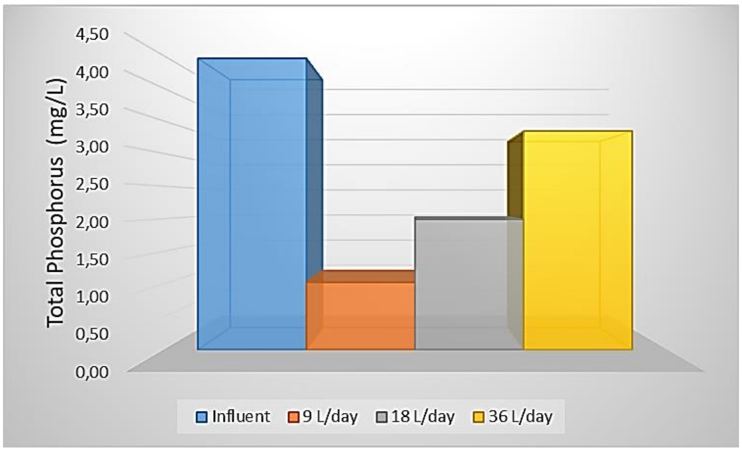


Figure 4.44 A soil column TP results.

A soil column is observed to provide phosphorus removal similar to a Ş soil column. The average TP value of influent water has found to be 4.45 ± 2.01 mg/L. The highest removal efficiency of P concentration in wastewater has obtained in the soil column fed with 9 L/day flow rate.

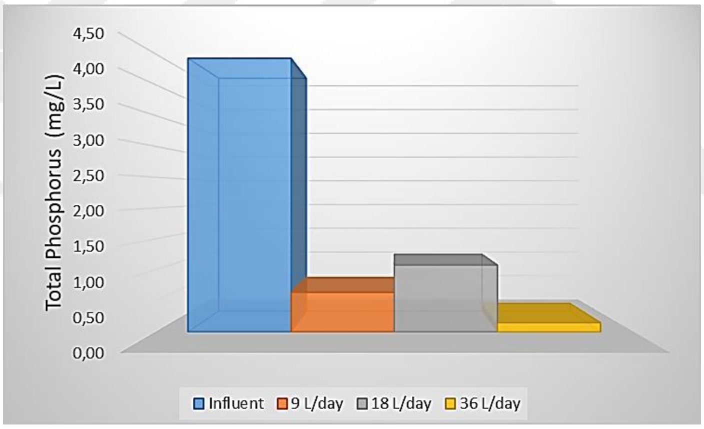


Figure 4.45 G soil column TP results.

The average amount of phosphorus in the influent water of G soil column has found to be 4.42 ± 1.38 mg/L. This value has decreased by an average of 0.15 ± 0.22 mg/L in the soil column effluent water fed with 36 L/day flow rate. The phosphorus concentration maximum retention rate for the G soil column has found to be about 96.50%. It can be stated that the efficiency of phosphorus retention in the soil column operating with 18 L/day flow rate is lower than the other columns.

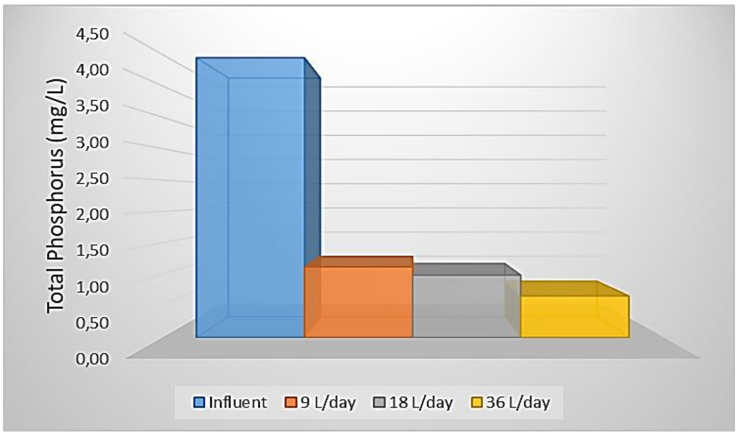


Figure 4.46 K soil column TP results.

The average phosphorus values of K soil column effluent water have found to be 1.12 ± 1.50 mg/L, 0.99 ± 0.70 mg/L and 0.66 ± 0.76 mg/L at flow rate 9 L/day, 18 L/day and 36 L/day, respectively. The phosphorus retention efficiency of soil K has been calculated to minimum 75%. The maximum 87% phosphorus has retained in the soil column fed with 36 L/day flow rate.

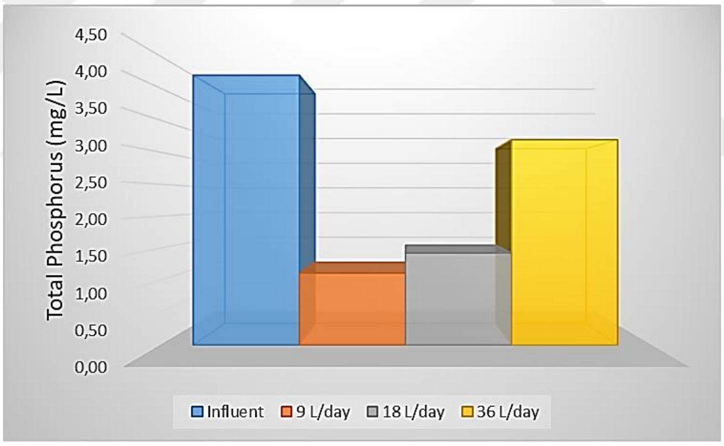


Figure 4.47 Ş soil column TP results.

The average phosphorus values of Ş soil column effluent water have found as 1.12 ± 0.34 mg/L, 1.43 ± 1.17 mg/L and 3.19 ± 1.25 mg/L at flow rate 9 L/day, 18 L/day and 36 L/day, respectively. When the Figure 4.47 is examined, it is seen that the phosphorus retention ratio of the soil columns decreases as the flow rate increases. When soil columns influent water phosphorus concentration is compared to average effluent water concentrations, minimum 24% and maximum 73% removal efficiency has been achieved.

When the Figure 4.44, 4.45, 4.46 and 4.47 are examined, the highest phosphate removal efficiency has obtained in the G soil column fed with 36 L/day flow rate at 96.50% and the lowest phosphate removal efficiency has obtained in the Ş soil column fed with 36 L/day flow rate of 24%. It is observed that the average phosphorus values of the influent water of the soil columns are close to each other. Here, soil structure and characteristic features stand out in terms of contaminant retention efficiency.

In previous studies were stated that phosphorus removal in wastewater depends not only on absorption but also on the rate of the flow system. In addition, the short and long term phosphorus absorption capacities of soils can vary greatly (Sawhney and Hill, 1975).

Hsieh and Davis (2005) showed variable phosphorus removals that did not correlate well with the measured media properties in their study with different media columns. Davis et. al. (2001) showed that approximately 80% of the dissolved phosphorus was removed by the sandy loam soil in laboratory scale a cell. Similar study demonstrated 70 to 85% phosphorus removal associated with media depth in pilot and full-scale soil facilities (Davis et. al., 2006).

In another study, influent water was continuously pumped onto three different soil columns and wastewater was collected from the bottom of the column everyday for a total of 29 days. During the first 6 days was observed that the influent and effluent phosphorus concentrations were close to each other. Then, optimum phosphorus removal varying between 67% and 98% was achieved (Hsieh et. al., 2007).

4.3.8 Total Nitrogen (TN)

In addition to phosphorus, another substance that is an important pollution parameter is nitrogen. The average nitrogen value obtained for each filtration alternative is given in the Table 4.15.

Table 4.15 The average TN values as results of soil column filtration (mg/L).

Soil Type	Influent	9 L/day	18 L/day	36 L/day
A soil-column	52.40 ± 9.88	8.21 ± 8.98	15.51 ± 12.50	46.00 ± 14.16
G soil-column	41.08 ± 11.95	2.90 ± 3.32	8.00 ± 7.81	2.30 ± 2.86
K soil-column	62.90 ± 16.84	28.80 ± 28.71	16.60 ± 15.54	18.30 ± 23.78

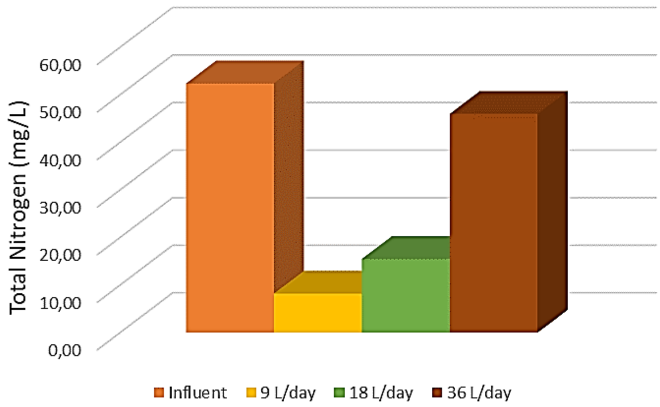


Figure 4.48 Average TN result of A soil column.

When Figure 4.48 is examined, the average TN value of the effluent water of the soil column fed with 36 L/day flow rate has been observed very close to the influent water. TN retention rate of this column is approximately 12.4%. The TN retention rate of the soil column fed with 9 L/day and 18 L/day flow has found to be approximately 83% and 76%, respectively.

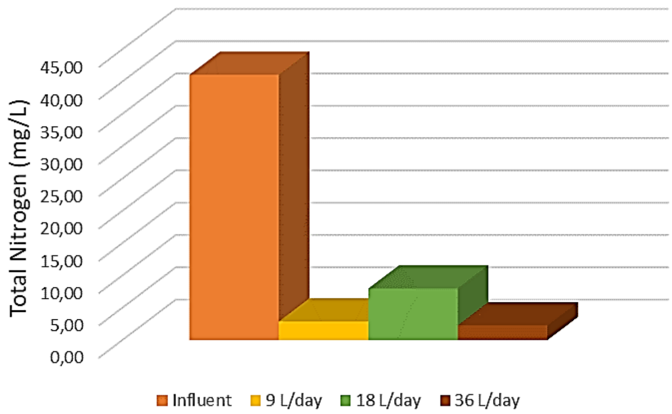


Figure 4.49 Average TN result of G soil column.

When the Figure 4.49 is examined, it is observed that the average TN value of the influent water of the G soil column is 41.08 ± 11.95 mg/L. TN removal efficiency of maximum 94.40% has achieved in the G soil column operated at different flow rates.

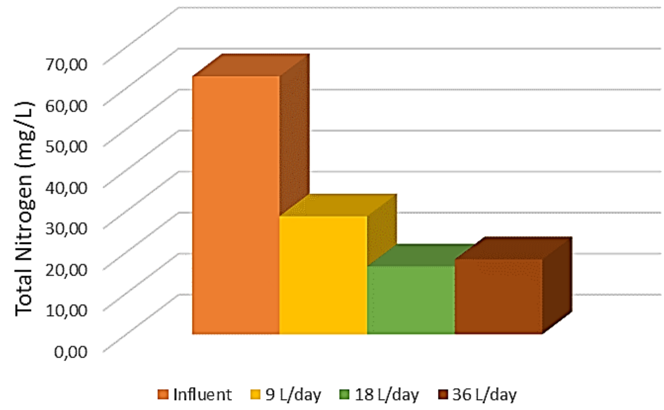


Figure 4.50 Average TN result of K soil column.

K soil column the average of the influent and effluent water can be stated to be relatively high compared to other soil columns. The minimum of 54.50% TN removal from wastewater has been achieved by K soil columns. It has observed that the average TN removal of the soil column fed with 18 L/day flow rate is the highest.

TN analysis results are agreement with studies in the literature. Hunt (2003) noted TN removal efficiency ranging from 70% to 85% by laboratory studies. In different study estimated annual total nitrogen mass removal rate as 40% for 1.2 m fill media at conventionally drained (Hunt et. al., 2006). Lu et. al. (2015) stated that the average TN removal rate was 63.4% in their study. Kim et al. (2003) found substantial TN removal from column studies. It was stated that nitrogen was a parameter showing significant differences in a different column study conducted by Tonon et. al. (2015). Qin et. al. (2014) conducted a column study on three different fillings for rural sewage treatment. The TN removal efficiency of these columns was found to be 25%, 72% and 31%. Khanbilvardi and Long (1985) showed that the most significant reduction in nitrogen occurred in the first 30 cm of soil.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 General

In this study, the impacts of filtration of domestic wastewater on natural soils on both soil and wastewater treatment were examined. This section involves the results of the experimental studies conducted.

5.2 The effects of wastewater on natural soils

It is a natural phenomenon to benefit from the filtration properties of the soil in the treatment of wastewater. On the other hand, it is known that all kinds of organic and inorganic contaminants that reach the soil initiate an interaction with the soil and as a result, positive or negative transformation of the physical, chemical and mechanical properties of the soil occurs. For this reason, the determination of natural soil properties and impacts of wastewater on soil were examined before and after wastewater application. The properties of natural soils taken from four different regions with different gradations before and after wastewater filtration are summarized in Table 5.1.

Table 5.1 Properties of natural soils as a result of wastewater filtration.

	A		G		K		Ş	
Soil Properties	Before	After	Before	After	Before	After	Before	After
Sieve and Hydrometer Analysis								
Gravel (%)	10.27		5.37		19.56		5.22	
Sand (%)	24.24		22.00		21.79		8.46	
Silt (%)	36.10		34.91		35.46		59.17	
Clay (%)	29.39		37.72		23.19		27.15	
Classification	CL		CH		CL		CL	
$\omega_{natural}$ (%)	9.20		22.10		5.50		7.60	
Bulk Density (γ_n) (gr/cm^3)	1.70		1.76		1.85		1.89	
Porosity (n) (%)	38.30		34.40		29.80		30.40	
Consistency Limits								
LL (%)	48.9	47.1	53.4	51.2	38.3	42.1	45.1	48.9
PL (%)	23.4	24.5	27.7	28.0	21.3	22.3	23.4	23.8
PI (%)	25.5	22.6	25.7	23.2	17.0	19.8	21.7	25.1
G_s	2.76	2.74	2.69	2.68	2.64	2.67	2.72	2.69
Standart Compaction Test								
γ_{kmax} (ton/m^3)	1.60	1.61	1.53	1.56	1.66	1.63	1.61	1.60
ω_{opt} (%)	23.489	21.302	26.416	23.500	18.616	19.900	21.054	21.500
Unconfined Compressive Strength								
q_u (kPa)	203.60	192.6	227.05	216.80	195.45	183.58	186.70	175.70
ε (%)	1.90	2.09	5.38	4.95	3.00	2.50	3.18	2.77
Permeability (cm/sn)	9.16x10-^{9}	4.65x10^{-9}	5.95x10-^{9}	7.00x10^{-9}	9.64x10^{-9}	1.06x10^{-8}	1.17x10-^{8}	1.36x10^{-8}

As a result of Atterberg limits, LL and PI of soils G and A decreased and PL increased. LL, PL and PI of soils Ş and K were found to be increased. It has been observed that the PL increase of soils is at maximum 5%. It is seen that the maximum increase in LL and PI values is 10% and 16.5%, respectively, while the maximum decrease is 4.12% and 11.5%, respectively. This increase or decrease in Atterberg limits can be explained by the chemical interaction between soil particles and wastewater. This interaction may change depending on the type and amount of clay minerals in the soil. In addition, contaminants with a higher viscosity compare with water may have increased particle-particle or particle-pore fluid interaction power, leading to greater water absorption. As the water content of the soils increases, the cohesion of the clay grains decreases with moving away from each other. Therefore, the self-holding structure of the soil begins to deteriorate. As a result, the strength of the soil decreases and shear and settlements begin to occur. The smaller the LL, PL and PI values of the soils need the less soil improvement. It can also be said that the increase in Na^+ or salt concentration in relation to the chemical element concentrations of the soil due to the effect of infiltration may cause an increase in soil water retention. Therefore, elemental analyses were conducted in order to evaluated chemical composition of soils used in experiment. The elements Na, Ca, Mg, P, K and N found in trace amounts in the soil texture were determined by elemental analyses. After that, SAR values were calculated depending on the concentration of Na, Ca and Mg elements in order to express the soil salinity. An increase has been observed in almost all element concentrations of G and Ş soils. Moreover, SAR increased due to Na increase Ca or Mg decrease in A and K soil. Therefore, the salinity of soils has increased by 131.88% - 180.70% with wastewater infiltration. It is possible to associate the amount of salt in the soil structure with physical, mechanical and chemical properties of the soil such as water content, water absorption capacity, compaction and permeability.

When the compaction results were evaluated, no significant change was observed in the maximum dry density of A and Ş soils. The dry density of soil G increased and the optimum water content decreased whereas in soil K decreased in dry density and increased in the optimum water content. The purpose of compaction is to achieve maximum dry density with less energy. It can be said that soils with high contaminant concentrations and water content can be difficult to compaction of the soil at the same energy compared to uncontaminated soil and lower dry density can be obtained.

As a result of the wastewater filtration, a certain amount of decrease was observed in the unconfined compressive strength of all soils. The unconfined compressive strength decreased approximately in G and K soils 4.5% and 6.1%, respectively. It decreased approximately 5.9% in Ş and A soils. The dispersion or fragmentation of fine particles which are connected to each other in the soil structure by wastewater leakage can cause a decrease in the unconfined compressive strength. Hence, when the SEM imaging results are examined, it has been found that the compact structure of the particles changed to a certain extent.

In the permeability test results, the permeability of the G, Ş and K soils increased with the interaction of wastewater while the permeability of soil A decreased slightly. When the pores of the soil begin to fill with chemical precipitation, the permeability capacity of the soil decreases. In addition, water with a high degree of hardness can cause fine particles to come together. Thus, the permeability of the soil can be reduced. When the water flows on the soil, it can drag the soil grains away. This time, the opposite situation is observed in permeability. The unstable situation caused by the leaking water in the soil mass under certain conditions can create pores in the soil interior structure. Therefore, it causes an increase in the permeability of the soil. This increase in permeability may indicate that the impermeability property of the soil may deteriorate. It can be said that the increase in the permeability value of the soil may cause the treatment capacity of the wastewater to decrease.

5.3 The effects of natural soils on wastewater treatment

Methods such as seepage pits, wastewater tanks, septic tanks and rapid infiltration can be applied to prevent the leakage of wastewater directly into the soil. These methods can be used especially in rural areas without a central sewage system and in less populated residential areas. The operation principle of these systems is generally based on the wastewater leaking to the soil by pre-sedimentation. Thus, the infiltration and treatment capacity of domestic wastewater into natural soils has been evaluated. The results of COD, SS, TP and TN are given in Table 5.2.

Table 5.2 Total removal rate of average concentration of effluent samples.

Soil Type	***Effluent Samples***	**COD (%)**	**SS (%)**	**TP (%)**	**TN (%)**
A soil column	9 L/day	72.0	97.0	76.8	83.0
	18 L/day	80.5	94.2	55.3	76.0
	36 L/day	36.2	84.4	24.9	12.4
G soil column	9 L/day	89.9	95.8	85.5	92.9
	18 L/day	90.0	95.2	75.6	80.5
	36 L/day	84.1	97.2	96.6	94.4
K soil column	9 L/day	81.8	99.3	74.8	54.5
	18 L/day	78.5	96.8	77.7	73.6
	36 L/day	84.7	97.9	85.1	70.9
Ş soil column	9 L/day	78.3	97.9	73.3	
	18 L/day	72.2	94.6	65.9	
	36 L/day	55.1	91.7	23.9	

When Table 5.2 is examined, it can be said that all natural soil types are effective in removing contaminants from wastewater. COD was retained in A soil at a minimum of about 36%, while a maximum of 90% in G soil. Suspended solids (SS) retention rate is over 90% for almost all soils. The highest SS retention average observed in K soil column. Soil filtration also lead to decrease in the COD value by removing high levels of organic particles or suspended solids from the wastewater. Furthermore, the discharge standards specified in Table 4.11 were reached for COD and SS parameters.

Phosphorus removal rates of soils from wastewater varied between 23.9-96.6%. G soil has the highest TP retention rate. The lowest TP retention rate was found in soil Ş fed with 36 L/day flow and then soil A. Soils with a certain fine structure and therefore a larger specific surface area can be effective in filtration. Since these soils have high water absorption capacity, contaminant retention rate may also be high. Therefore, soil G is the soil with the highest clay content at about 38%. Soil G has shown a high performance in the increase in treatment of all contaminants among the other soils. In addition, the CH soil type may have strong interaction with wastewater than the CL soil type. Nitrogen removal rate of the soils varied between 12.4% and 94.4%.

The pH measurement ranges of the effluent water of the soil columns were found between 7.59-8.29. It is necessary to adjust the pH value of the wastewater treated according to Table 4.11 to the range of 6-9 before being introduced into the receiving environment. For this reason, it can be said that the column effluent water comply with the discharge standards. When the results of conductivity measurements which is another water quality parameter are examined, the lowest conductivity values (below the average 1000 μS/cm) have been reached in the G soil column filtration corresponding to the winter season. In the conductivity results of A soil filtration, the highest values (average 2000 μS/cm) were measured. Conductivity measurement results were classified as 'lightly polluted' and 'polluted water' according to water quality criteria (e-Legislation no: 28483).

Elemental analyzes of wastewater were performed to determine hardness and SAR parameters. As a result of soil filtration, average wastewater hardness was found to be the highest 681.86 mg/L and the lowest 235.73 mg/L. These results showed that the hardness levels of the effluent water are high (Table 3.6). Results of SAR value, which is a measure of the harmfulness of water in terms of sodium or salt were shown in detail in Table 4.13. The highest average influent and effluent water in terms of SAR was found in the A soil column. Moreover, it has been observed that soil A has the highest average hardness levels. An unstable structure may have formed between soil A and wastewater interaction. Substances that can easily dissolve or degrade in soil structure can affect the SAR and hardness of the wastewater and all other water quality parameters.

Finally, studies have been conducted to show that as the contact time of the soil with the contaminant increases, the contaminant removal rate increases (Easter et. al., 2005). Partially at higher flow rates, the contact time of wastewater with soil is reduced and effluent water with higher contaminant concentrations can be obtained (Bradford et. al., 2003). Nevertheless, as can be reached at the end of this study, it has been stated that efficiency can be achieved at a higher flow rate in literature (Xu et. al., 2006). This leads to the conclusion that it can affect the filtration in many different variables.

5.4 Recommendations

As a result of soil experiments, it was observed that the physical, chemical and mechanical properties of the soil partially changed in the short term. According to the results obtained in the short term, it may be possible to reuse the soils used in the filtration area for previous purposes or to be used as a backing layer, engineering filling, improved material and covering the filled soil. However, it can be stated that it should be evaluated in longer term for further researches. In the long term, when the soil of the area where wastewater has been applied is considered to be used for a different purpose, it may be necessary to determine its characteristics and to stabilize the soil which is in unsuitable conditions.

The most important structural parameter in filtration is permeability. Only vertical flow can be evaluated with soil column tests. It is known that the permeabilities in the horizontal and vertical directions are different from each other in natural soil layers. For this reason, it may be recommended to roughly review the flow network in field conditions.

Treatment of wastewater with conventional methods becomes increasingly difficult and requires significant treatment costs. In this respect, soil filtration can be considered in rural areas with a low hydraulic loading rate and a uniform distribution method in order to discharge of low contaminated water. The correct design and use of filtration under appropriate conditions can gain value day by day in terms of cost and operating costs. It can be recommend that further studies should try various treatment combinations and use the water obtained in the process again.

REFERENCES

Abedi-Koupai, J., Mostafazadeh-Fard, B., Afyuni, M. and Bagheri, M. R. (2006). Effect of treated wastewater on soil chemical and physical properties in an arid region. Plant Soil and Environment, 52, 2006(8), 335-344.

Abreu, A. E. S. and Vilar, O. M. (2017). Influence of composition and degradation on the shear strength of municipal solid waste. Waste Management, 68(2017), 263-274.

Abo-El-Enein, A. S., Ali, H. A., Talkhan, N. F. and Abdel-Gawwad, A. H. (2012). Utilization of microbial induced calcite precipitation for sand consolidation and mortar crack remediation. HBRC Journal, 8(2012), 185-192.

Abiye, T. A., Sulieman, H. and Ayalew, M. (2009). Use of treated wastewater for managed aquifer recharge in highly populated urban centers: A case study in Addis Ababa, Ethiopia. Environmental Geology, 58(1), 55-59.

Ahn, K. H. and Song, K. G. (1999). Treatment of domestic wastewater using microfiltration for reuse of wastewater. Desalination, 126(1-3), 7-14.

Aiello, R., Cirelli, G. L. and Consoli, S. (2007). Effects of reclaimed wastewater irrigation on soil and tomato fruits: A case study in Sicily (Italy). Agricultural Water Management, 93(2007), 65-72.

Alhassan, M. H. and Fagge, A. S. (2013). Effects of crude oil, low point pour fuel oil and vacuum gas oil contamination on the geotechnical properties sand, clay and laterite soils. International Journal of Engineering Research and Applications (IJERA), ISSN:2248-9622, Vol.3, Issue:1, 1947-1954.

Al-Othman, A. A. (2009). Effect of treated domestic wastewater on physical and chemical characteristics of soils. Journal of Applied Sciences 9(5): 901-908, 2009, ISBN:1812-5654.

Al-Sanad, A. H., Eid, K. W. and Ismael, F. N. (1995). Geotechnical properties of oil-contaminated Kuwaiti sand. Journal of Geotechnical Engineering, DOI:10.1061/(ASCE)0733-9410(1995)121:5(407).

Amiri, V., Rezaei, M. and Sohrabi, N. (2014). Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. Environmental Earth Sciences, November 2014, Vol.72, Issue 9, 3479-3490.

Ak, M. and Top, I. (2018). Use of treated municipal wastewater for agricultural irrigation. Pamukkale University Journal of Engineering Sciences, 24(6), 1161-1168, 2018, (Turkish).

Akhtar, N. M. (2012). Role of soil mechanics in civil engineering. International Journal of Emerging trends in Engineering and Development, Issue 2, Vol.6, 104-111, ISSN 2249-6149.

Alobaidy, A. H. M. J., Al-Sameraiy, M. A., Kadhem, A. J. and Majeed, A. A. (2010). Evaluation of treated municipal wastewater quality for irrigation. Journal of Environmental Protection, 1(03), 216.

Asian Development Bank. (2012). Promoting beneficial sewage sludge utilization in the people's republic of china. Asian Development Bank, Mandaluyong City, Philippines. Available at: http://gwp.org/Global/ToolBox/References/Promoting %20sustainable%20sewage%20utilization%20in%20PRC%20 (ADB, 2012).pdf.

Bache, W. B., Rosenqvist, Th. I., Goldsmith, P., Fowler, D., Ogden, G. J., III and Brown, A. K. (1984). Soil-water interactions. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, Vol. 305, No. 1124, 393-407.

Balasubramanian, A. (2017). Physical properties of soils. ResearchGate, Technical Report, DOI:10.13140/RG.2.2.24150.24648.

Barrett, M. E. (2003) Performance, cost and maintenance requirements of austin sand filters. J. Water Res. Planning Mgmt., ASCE, 129(3), 234-242.

Basu, D., Misra, A., Puppala, A. J. and Chittoori, C. S. (2013). Sustainability in geotechnical engineering. Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris 2013.

Bedbabis, S., Rouina, B. B., Boukhris, M. and Ferrara, G. (2014). Effect of irrigation with treated wastewater on soil chemical properties and infiltration rate. Journal of Environmental Management, 133, 45-50.

Berry, K. A. T. and Burton, D. L. (1997). Natural attenuation of diesel fuel in heavy clay soil. Can. J. Soil. Sci, 77:469-477.

Bester, K. and Schäfer, D. (2009). Activated soil filters (bio filters) for the elimination of xenobiotics (micro-pollutants) from storm and wastewater. Water Research, 43(10), 2639-2646.

Bharti, K. P., Kumar, P. and Singh, V. (2013). Impact of industrial effluents on ground water and soil quality in the vicinity of industrial area of Panipat city, India. Journal of Applied and Natural Science, (2013)5(1):132-136.

Bourrie, G. (2014). Swelling clays and salt-affected soils: Demixing of Na/Ca clays as the rationale for discouraging the use of sodium adsorption ratio (SAR). Eurasian Journal of Soil Science, 3(2014), 245-253.

Boysan, F. and Şengörür, B. (2009). The importance of water hardness for human health. Sakarya University Journal of Science (SAUJS), 13(1), 7-10, (Turkish).

Bradford, S. A., Simunek, J., Bettahar, M., Van Genuchten, M. T. and Yates, S. R. (2003). Modeling colloid attachment, straining, and exclusion in saturated porous media. Environmental Science & Technology, 37(10), 2242-2250.

Bremner, J. M. (1965). Organic nitrogen in soils. Soil Nitrogen, 10, 93-149.

Bulun, G. (2010). 3d transition metals Ni and lantanit Gd substituted $Zn_{1-x}O_x$ compounds of structural and magnetic properties. Doctoral Dissertation, Graduate School of Science, Physics Department, Cukurova University, (Turkish).

Candela, L., Fabregat, S., Josa, A., Suriol, J., Vigués, N. and Mas, J. (2007). Assessment of soil and groundwater impacts by treated urban wastewater reuse, A case study: Application in a golf course (Girona, Spain). Science of the Total Environment, 374(1), 26-35.

Carroll, S., Goonetilleke, A. and Dawes, L. (2004). Framework for soil suitability evaluation for sewage effluent renovation. Environmental Geology, 46(2):195-208.

Carroll, S., Goonetilleke, A., Thomas, E., Hargreaves, M., Frost, R. and Dawes, L. (2006). Integrated risk framework for onsite wastewater treatment systems. Environmental Management, 38(2), 286-303.

Chakraborty, S., Jo, B. W., Jo, J. H. and Baloch, Z. (2017). Effectiveness of sewage sludge ash combined with waste pozzolanic minerals in developing sustainable construction material: An alternative approach for waste management. Journal of Cleaner Production, 153, 253-263.

Chavali, P. V. R. and Ponnapureddy, R. P. H. (2018). Swelling and compressibility characteristics of bentonite and kaolin clay subjected to inorganic acid contamination. International Journal of Geotechnical Engineering, Vol:12, Issue:5, 500-506, DOI:10.1080/19386362.2017.1299418.

Chegenizadeh, A. and Nikraz, H. (2011). Permeability test on reinforced clayey sand. World Academy of Science, Engineering and Technology 78, 2011, 130-133.

Chen, F. H. (1988). Foundations on expansive soils. Elsevier, Amsterdam, the Netherlands.

Chen, Q., Xie, W. and Liu, N. (2018). Industrial wastewater treatment technology and prospect. Applied Chemical Engineering, (2018), EnPress.

Chen, Y. and Banin, A. (1975). Scanning electron microscope (SEM) observations of soil structure changes induced by sodium-calcium exchange in relation to hydraulic conductivity. Soil Science, 120(6), 428-436.

Chen, Y., Wang, C. and Wang, Z. (2005). Residues and source identification of persistent organic pollutants in farmland soils irrigated by effluents from biological treatment plants. Environment International, 31(6), 778-783.

Chun, Y. E., Zhan-Bo, H. U., Hai-Nan, K. O. N. G., Xin-Ze, W. A. N. G. and Sheng-Bing, H. E. (2008). A new soil infiltration technology for decentralized sewage treatment: Two-stage anaerobic tank and soil trench system. Project Supported by the National High Technology Research and Development Program (863 Program) of China (No.2002AA601012-01). Pedosphere, 18(3), 401-408.

Cemek, B. and Oktaş, R. (2020). Evaluation of quality of groundwater in irrigation using fuzzy logic in the Bafra Plain, Northern Turkey. Eurasian Journal of Soil Science, 9(4), 339-348.

Cirik, K. and Eskikaya, O. (2018). Characterization of Kahramanmaras central wastewater treatment plant influent. Kahramanmaras Sutcu Imam University, Journal of Engineering Sciences, 21(4):286-294, 2018, (Turkish).

Cooper, J. A. (2016). Onsite wastewarer treatment systems in a changing climate: technology robustness and mechanisms. Doctor of Phisolophy in Biological and Envrionmental Sciences, University of Rhode Island.

Cyrus, S., Kumar, T. G. S., Abraham, B. M., Sridharan, A. and Jose, B. T. (2010). Effect of industrial wastes on the physical and engineering properties of soils. Indian Geotechnical Conference- December,16-18, 2010.

Daka, R. M. (2015). Geotechnical properties of oil contaminated soil. The University of Manchester, Master of Philosophy, The Faculty of Engineering and Physical Sciences, 2015.

Das, R. and Das, N. S. (2003). Impact of wastewater discharge on soil and ground water - A case study. Journal of Scientific and Industrial Research (JSIR), Vol.62(03), 207-211.

Davis, A. P., Shokouhian, M., Sharma, H. and Minami, C. (2001). Laboratory study of biological retention for urban stormwater management. Water Environ. Res., 73, 5-14.

Davis, A. P., Shokouhian, M., Sharma, H. and Minami, C. (2006). Water quality improvement through bioretention media: nitrogen and phosphorus removal. Water Environ. Res., 78(3), 284-293.

Dawes, L. and Goonetilleke, A. (2003). An investigation into the role of site and soil characteristics in onsite sewage treatment. Environmental Geology, 44(4), 467-477.

DeJong, J. T., Mortensen, B. M., Martinez, B. C. and Nelson, D. C. (2010). Bio-mediated soil improvement. Ecological Engineering, 36(2), 197-210.

Dempster, N. D., Jones, L. D. and Murphy, V. D. (2012). Clay and biochar amendments decreased inorganic but not dissolved organic nitrogen leaching in soil. Soil Research, (2012)50, 216-221.

Deneele, D., Cuisinier, O., Hallaire, V. and Masrouri, F. (2010). Microstructural evolution and physico-chemical behavior of compacted clayey soil submitted to an alkaline plume. Journal of Rock Mechanics and Geotechnical Engineering, (2010), 2(2): 169-177.

De Oliveira Silva, J., Rodrigues Filho, G., da Silva Meireles, C., Ribeiro, S. D., Vieira, J. G., da Silva, C. V. and Cerqueira, D. A. (2012). Thermal analysis and FTIR studies of sewage sludge produced in treatment plants. The case of sludge in the city of Uberlândia-MG, Brazil. Thermochimica Acta, 528, 72-75.

Dirckx, G., Van Daele, S. and Hellinck, N. (2016). Groundwater infiltration potential (GWIP) as an aid to determining the cause of dilution of wastewater. Journal of Hydrology, 542:474-486.

Doğanay, E. (2014). The evaluation of analysis methods to be used for monitoring of the water in our country within the scope of EU water framework directive from the point of physicochemical and chemical parameters. Republic of Turkey, Ministry of Forestry and Water Affairs, General Directorate of Water Management, Thesis of Expertise, 205, (Turkish).

Dolinar, B. and Trauner, L. (2004). Liquid limit and specific surface of clay particles. Geotechnical Testing Journal, 27(6), 580-584.

Duan, R., Sheppard, D. C. and Fedler, B. C. (2010). Short-term effects of wastewater land application on soil chemical properties. Water Air Soil Pollut., 211(2010):165-176, DOI:10.1007/s11270-009-0290-7.

Duborsk, E., Urík, M., Bujdos, M. and Matulova, M. (2019). Influence of physicochemical properties of various soil types on iodide and iodate sorption. Chemosphere, 214(2019), 168-175.

Dudziak, M. and Kudlek, E. (2019). Removal of hardness in wastewater effluent using membrane filtration. Architecture Civil Engineering Environment, 12(2).

Easter, C., Quigley, C., Burrowes, P., Witherspoon, J. and Apgar, D. (2005). Odor and air emissions control using biotechnology for both collection and wastewater treatment systems. Chemical Engineering Journal, 113(2-3), 93-104.

Edil, T. B. and Fox, P. J. (2000). Geotechnics of high water content materials. STP 1374, Publisher: American Society for Testing and Materials. West Conshohocken. DOI: 10.1520/STP1374-EB.

Ellis, J. B. (2001). Sewer infiltration/exfiltration and interactions with sewer flows and groundwater quality. Interactions between Sewers, Treatment Plants and Receiving Waters in Urban Areas e INTERUBA II, 311-319.

El-Sayed, M. and Salem, W. M. (2015). Hydrochemical assessments of surface Nile water and ground water in an industry area–South West Cairo. Egyptian Journal of Petroleum, 24(3), 277-288.

Erarslan, İ. (2003). Effects of toxic leachates on compacted clay liners. Master Thesis, Institute of Science, Istanbul University, (Turkish).

Estabragh, R. A., Beytolahpour, I., Moradi, M. and Javadi, A. A. (2014). Consolidation behavior of two fine-grained soils contaminated by glycerol and ethanol. Engineering Geology, 178(2014), 102-108.

Fernandez, F. and Quigley, R. M. (1985). Hydraulic conductivity of natural clays permeated with simple liquid hydrocarbons. Canadian Geotechnical Journal, 22(2), 205-214.

Foster, S., Lawrence, A. and Morris, B. (1998). Groundwater in urban development: Assessing management needs and formulating policy strategies. World Bank Technical Paper No:390. The World Bank, Washington, ISBN:0-8213-4072-7.

Foster, S. (2001). The interdependence of groundwater and urbanization in rapidly developing cities. Urban Water, 2001;3:185-92.

Franco, D., Lee, J., Arbelaez, S., Cohen, N. and Kim, J. Y. (2017). Removal of phosphate from surface and wastewater via electrocoagulation. Ecological Engineering, 108, 589-596.

Gagan, M., Amit, C., Avinash, K. and Ajendra, K. (2016). Impact of industrial effluent on ground water and surface water quality - A case study of Dhampur region (U.P.), India. Journal of Chemical and Pharmaceutical Sciences, 9(2):709-713.

Gao, J., Chen, S., Wang, W., Yan, Q., Jiang, N. and Ruiqin, Z. (2012). Effects of unpowered complex eco-technology on sewage purification in central chinese rural areas. Polish Journal of Environmental Studies, 21(6).

Ghembaza, S. M., Taïbi, S. and Fleureau, M. J. (2015). New thermal triaxial apparatus for unsaturated soils using the osmotic method. Arab J.Geosci, 8(2015):3365-3380, DOI:10.1007/s12517-014-1471-2.

Ghosh, R. (2013). Effect of soil moisture in the analysis of undrained shear strength of compacted clayey soil. Journal of Civil Engineering and Construction Technology, Vol. 4(1), 23-31, DOI:10.5897/JCECT12.070.

Galavi, M., Jalali, A., Ramroodi, M., Mousavi, S. R. and Galavi, H. (2010). Effects of treated municipal wastewater on soil chemical properties and heavy metal uptake by sorghum (Sorghum bicolor L.). Journal of Agricultural Science, 2(3), 235.

Goonetilleke, A., Dawes, L. and Biddel, D. (2002). Performance evaluation of septic tanks in the Gold Coast region. Environmental Studies, Copyright 2002 Gold Coast City Council, Research Unit, Vol, 8. Australia.

Graham, J., Yuen, K., Goh, B. T., Janzen, P. and Sivakumar, V. (2001). Hydraulic conductivity and pore fluid chemistry in artificially weathered plastic clay. Engineering Geology, 60(2001), 69-81.

Green, J. W., Lee, F. G. and Jones, A. R. (1981). Clay-soils permeability and hazardous waste storage. Article in Journal of the Water Pollution Control Federation, 53(1981):1347-1354, DOI:10.2307/25041482.

Gross, M. A. (1984). Septic tank virus removal by sand filtration. The University of Arkansas, Doctor of Philosophy Thesis, May, 1984.

Gu, B., Fan, L., Ying, Z., Xu, Q., Luo, W., Ge, Y., ... and Chang, J. (2016). Socioeconomic constraints on the technological choices in rural sewage treatment. Environmental Science and Pollution Research, 23(20), 20360-20367.

Guo, L., Li, T., Chen, G., Yu, P., Peng, X. and Yang, D. (2019). A method for microscopic unsaturated soil-water interaction analysis based on DDA. Computers and Geotechnics, 108(2019), 143-151.

Guler, E., Ozhan, H. O. and Karaoglu, S. (2018). Hydraulic performance of anionic polymer-treated bentonite-granular soil mixtures. Applied Clay Science, 157, 139-147.

Hasan, H., Battikhi, A. and Qrunfleh, M. (2014). Impacts of treated wastewater reuse on some soil properties and production of gladiolus communis. Journal of Horticulture Vol. 1, Issue 3. DOI:10.4172/horticulture.1000111.

Hajdarwish, A., Shakoor, A. and Wells, A. N. (2013). Investigating statistical relationships among clay mineralogy, index engineering properties, and shear strength parameters of mudrocks. Engineering Geology, 159(2013), 45-58.

Horn, R., Taubner, H., Wuttke, M. and Baumgartl, T. (1994). Soil physical properties related to soil structure. Soil and Tillage Research, Vol.30, Issues 2-4, June 1994, 187-216.

Hsieh, C. H. and Davis, A. P. (2005). Evaluation and optimization of bioretention media for treatment of urban storm water runoff. Journal of Environmental Engineering, 131(11), 1521-1531.

Hsieh, C. H., Davis, A. P. and Needelman, B. A. (2007). Bioretention column studies of phosphorus removal from urban stormwater runoff. Water Environment Research, 79(2), 177-184.

Hua, J., An, P., Winter, J. and Gallert, C. (2003). Elimination of COD, microorganisms and pharmaceuticals from sewage by trickling through sandy soil below leaking sewers. Water Research, 37(2003), 4395-4404.

Hu, Q., Moran, J. E. and Blackwood, V. (2009). Geochemical cycling of iodine species in soils. Chapter-10, Comprehensive Handbook of Iodine, Oxford: Academic Press, 2009, 93-105, ISBN:978-0-12-374135-6.

Hunt, W. F. (2003). Pollutant removal evaluation and hydraulic characterization for bioretention stormwater treatment devices. Doctoral Thesis, Dept. of Agricultural and Biological Engineering, Pennsylvania State Univ., State College, Pa.

Hunt, W. F., Jarrett, A. R., Smith, J. T. and Sharkey, L. J. (2006). Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. Journal of Irrigation and Drainage Engineering, 132(6), 600-608.

Hunt, W. F., Jarrett, A. R. and Smith, J. T. (2003). Optimizing bio-retention design to improve denitrification in commercial site runoff. In World Water & Environmental Resources Congress, 2003, 1-10.

Husssein, M. S., Shihab, H. O., Ibrahim, S. S. and Ahmed, M. N. (2015). Interaction between kaolin and urea in organoclay and its impact on removing methylene blue from aqueous solution. World Journal of Nano Science and Engineering, 5;1-9.

Igbinosa, O. E. and Okoh, I. A. (2009). Impact of discharge wastewater effluents on the physico-chemical qualities of a receiving watershed in a typical rural community. Int. J. Environ. Sci. Tech., 6(2), 175-182, Spring 2009, ISSN: 1735-1472.

Ijimdiya, S. T. (2011). Effect of oil contamination on particle size distribution and plasticity characteristics of lateritic soil. Advanced Materials Research, Online:2011-10-24, ISSN:1662-8985, Vol.367, 19-25.

Irfan, M., Chen, Y., Ali, M., Abrar, M., Qadri, A. and Bhutta, O. (2018). Geotechnical properties of effluent-contaminated cohesive soils and their stabilization using industrial by-products. Processes, 6(2018), 203, DOİ:10.3390/pr6100203.

Ivanov, V. and Chu, J. (2008). Applications of microorganisms to geotechnical engineering for bioclogging and biocementation of soil in situ. Reviews in Environmental Science and Bio/Technology, 7(2), 139-153.

Jago-ona, B.A.K., Kaneko, S., Fujikurac, R., Fujiwara, A., Imaid, T., Matsumoto, T., ….. Taniguchia, M. (2008). Urbanization and subsurface environmental issues: An attempt at DPSIR model application in Asian cities. Science of The Total Environment, 407(2009), 3089-3104.

Jedari, C. and Hamidi, A. (2015). Index properties of clays contaminated with organic fluids. 4th Conference and Exhibition on Environmental Engineering, at Tehran, Iran, ResearchGate, https://www.researchgate.net/publication/283909806.

Jnad, I. (2000). Characterizing soil hydraulic properties in the drainfield o f a subsurface drip distribution system. Texas A&M University, Doctor of Philosophy Thesis, Civil Engineering, December 2000.

Jnad, I., Lesikar, B., Sabbagh, G. and Kenimer, A. (2001). Soil clogging in a subsurface drip drain field. In On-Site Wastewater Treatment (p.18). American Society of Agricultural and Biological Engineers.

Johannes, A., Weisskopf, P., Schulin, R. and Boivin, P. (2017). To what extent do physical measurements match with visual evaluation of soil structure?. Soil and Tillage Research, 173(2017), 24-32.

Jones, D. L. and Jefferson, F. I. (2012). Geotechnical engineering principles, problematic soils and site investigation. ICE manual of geotechnical engineering. Vol.1, Chapter 5: Expansive Soils, Publisher: ICE Publishing, 413-441.

Kadam, A. M., Nemade, P. D., Oza, G. H. and Shankar, H. S. (2009). Treatment of municipal wastewater using laterite-based constructed soil filter. Ecological Engineering, 35(7), 1051-1061.

Kalantary, F. and Kahani, M. (2015). Evaluation of the ability to control biological precipitation to improve sandy soils. Procedia Earth and Planetary Science, 15:278-284.

Karkush, M. O. and Resol, J. A. D. (2015). Studying the effects of industrial wastewater on chemical and physical properties of sandy soil. Journal of Babylon University Engineering Sciences, No(2)/Vol(23):2015.

Karpf, C. and Krebs, P. (2011). Quantification of groundwater infiltration and surface water inflows in urban sewer networks based on a multiple model approach. Water research, 45(10), 3129-3136.

Karim, Z., Qureshi, A. B. and Mumtaz, M. (2015). Geochemical baseline determination and pollution assessment of heavy metals in urban soils of Karachi, Pakistan. Ecological Indicators, 48(2015), 358-364.

Keesstra, S. D., Geissen, V., Mosse, K., Piiranen, S., Scudiero, E., Leistra, M. and Van Schaik, L. (2012). Soil as a filter for groundwater quality. Current Opinion in Environmental Sustainability, 4(5), 507-516.

Kermani, M. and Ebadi, T. (2012). The effect of oil contamination on the geotechnical properties of fine-grained soils. Soil and Sediment Contamination: An International Journal, 21:5, 655-671, DOI:10.1080/15320383.2012.672486.

Khadge, H. N. (2005). Changes in geotechnical properties of sediments from the central Indian Basin induced by disturbance experiment. Marine Georesources and Geotechnology, 23(2005):401-417, DOI:10.1080/10641190500446797.

Khademi, F. and Budiman, J. (2016). Expansive soil: Causes and treatments. i-manager's Journal on Civil Engineering, Vol. 6, No. 3, June-August 2016.

Khan, M. I., Irfan, M., Aziz, M. and Khan, A. H. (2017). Geotechnical characteristics of effluent contaminated cohesive soils. Journal of Environmental Engineering and Landscape Management, 25(1), 75-82.

Khanbilvardi, R. M. and Long, D. A. (1985). Effect of soil depth on wastewater renovation. Journal of Environmental Health, 184-188.

Klay, S., Charef, A., Ayed, L., Houman, B. and Rezgui, F. (2010). Effect of irrigation with treated wastewater on geochemical properties (saltiness, C, N and heavy metals) of isohumic soils (Zaouit Sousse perimeter, Oriental Tunisia). Desalination, 253(1-3), 180-187.

Kim, H., Seagren, E. A. and Davis, A. P. (2003). Engineered bioretention for removal of nitrate from stormwater runoff. Water Environment Research, 75(4), 355-367.

Kim, S. H., Kim, R. K., Lee, H. S., Kunhikrishnan, A., Kim, W. and Kim, H. K. (2018). Effect of gypsum on exchangeable sodium percentage and electrical conductivity in the Daeho reclaimed tidal land soil in Korea-A field scale study. J, Soils Sediments, 18(2018):336-341. DOI 10.1007/s11368-016-1446-x.

Krzeminski, P., Leverette, L., Malamis, S. and Katsou, E. (2017). Membrane bioreactors-A review on recent developments in energy reduction, fouling control, novel configurations, LCA and market prospects. Journal of Membrane Science, 527(2017), 207-227.

Läuchli, A. and Epstein, E. (1990). Plant responses to saline and sodic conditions. Agricultural salinity assessment and management, 71, 113-137.

Lado, M. and Ben-Hur, M. (2009). Treated domestic sewage irrigation effects on soil hydraulic properties in arid and semiarid zones: A review. Soil and Tillage Research, 106(1), 152-163.

Lesmes, D. P. and Friedman, S. P. (2005). Relationships between the electrical and hydrogeological properties of rocks and soils. In: Rubin, Y., Hubbard, S. S. (Eds.), Hydrogeophysics. Water Science and Technology Library. Vol. 50 Springer, Dordrecht, Online ISBN: 978-1-4020-3102-1.

Lewis, J. and Sjöstrom, J. (2010). Optimizing the experimental design of soil columns in saturated and unsaturated transport experiments. Journal of Contaminant Hydrology, 115(2010), 1-13.

Li, H., Li, Y., Sun, T. and Wang, X. (2012). The use of a subsurface infiltration system in treating campus sewage under variable loading rates. Ecological Engineering, 38(1), 105-109.

Li, J., Zhou, H., Wang, Y., Xie, X. and Qian, K. (2017). Sorption and speciation of iodine in groundwater system: The roles of organic matter and organic-mineral complexes. Journal of Contaminant Hydrology, 201(2017), 39-47.

Li, Y. H., Li, H. B., Xu, X. Y., Gong, X. and Zhou, Y. C. (2015). Application of subsurface wastewater infiltration system to on-site treatment of domestic sewage under high hydraulic loading rate. Water Science and Engineering, 8(1), 49-54.

Ling, Y., Fanlong, K., Min, X., Yue, L. and Yuanyuan, Z. (2016). Emergy analysis of typical decentralized rural sewage treatment system: A case study of soil rapid infiltration in Qingdao, China. Journal of Resources and Ecology, 7(4), 309-316.

Loy, S., Assi, T. A., Mohtar, H. R., Morgan, C. and Jantrania, A. (2018). The effect of municipal treated wastewater on the water holding properties of a clayey, calcareous soil. Science of the Total Environment, 643(2018), 807-818.

Lu, S., Pei, L. and Bai, X. (2015). Study on method of domestic wastewater treatment through new-type multi-layer artificial wetland. International Journal of Hydrogen Energy, 40(34), 11207-11214.

Madsen, F. T. and Mitchell, J. K. (1989). Chemical effects on clay farbric and hydraulic conductivity. In The Landfill (pp. 201-251). Springer, Berlin, Heidelberg.

Maharaj, A. and Paige-Green, P. (2013). The SCS double hydrometer test in dispersive soil identification. Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, 389-392.

Martins, T., Leitão, T. E. and Carvalho, M. R. (2017). Assessment of wastewater contaminants retention for a Soil-Aquifer Treatment system using soil-column experiments. Procedia Earth and Planetary Science, 17(2017), 332-335.

Matichenkov, V. V., Bocharnikova, A. E., Pakhnenko, P. E. and Khomiakov, M. D. (2017). Effect of Si-rich substances on phosphorous adsorption by sandy soils. Environ Sci Pollut Res, (2017) 24:24311-24317, DOI:10.1007/s11356-017-0051-x.

Matong, J. M., Nyaba, L. and Nomngongo, P. N. (2017). Determination of As, Cr, Mo, Sb, Se and V in agricultural soil samples by inductively coupled plasma optical emission spectrometry after simple and rapid solvent extraction using choline chloride-oxalic acid deep eutectic solvent. Ecotoxicology and Environmental Safety, 135, 152-157.

Matteo, D. L., Bigotti, F. and Ricco, R. (2011). Compressibility of kaolinitic clay contaminated by ethanol-gasoline blends. Journal of Geotechnical and Geoenvironmental Engineering, DOI:10.1061/(ASCE)GT.1943-5606.0000494.

McDowell- Boyer, L. M., Hunt, J. R. and Sitar, N. (1986). Particle transport through porous media. Water Resources Research, 22(13), 1901-1921.

McIntyre, D. S. (1979). Exchangeable sodium, subplasticity and hydraulic conductivity of some Australian soils. Soil Research, 17(1), 115-120.

Meegoda, N. J. and Rajapakse, A. R. (1993). Short-term and long-term permeabilities of contaminated clays. Journal of Environmental Engineering, DOI:10.1061/(ASCE)0733-9372(1993)119:4(725-743).

Metzger, L., Yaron, B. and Mingelgrin, U. (1983). Soil hydraulic conductivity as affected by physical and chemical properties of effluents. Agronomie, EDP Sciences, 1983, 3 (8), 771-778.

Milovanovic, M. (2007). Water quality assessment and determination of pollution sources along the Axios/Vardar River, Southeastern Europe. Desalination, 213(2007):159-173.

Mishra, A. K., Ohtsubo, M., Li, L. Y., Higashi, T. and Park, J. (2009). Effect of salt of various concentrations on liquid limit, and hydraulic conductivity of different soil-bentonite mixtures. Environmental Geology, 57(5), 1145-1153.

Mitchell, J. K. and Madsen, F. T. (1987). Chemical effects on clay hydraulic conductivity. In Geotechnical Practice for Waste Disposal'87, (pp. 87-116). ASCE.

Mitropoulos, Ch. A. (2009). Capillarity. Journal of Engineering Science and Technology Review, 2(1), (2009), 28-32.

Mohamed, O. M. A. and Antia, E. H. (1998). Geoenvironmental engineering, Vol.82, 1st Edition, Imprint: Elsevier Science, ISBN: 9780080532448, 706.

Mojid, M. A., Hossain, A. B. M. Z. and Wyseure, G. C. L. (2019). Impacts of municipal wastewater on basic soil properties as evaluated by soil column leaching experiment in laboratory. Journal of Soil Science and Plant Nutrition, (2019)19:402-412, https://doi.org/10.1007/s42729-019-00042-x.

Mokhtari, M. and Dehghani, M. (2012). Swell-shrink behavior of expansive soils, damage and control. Electronic Journal of Geotechnical Engineering, EJGE, Vol. 17(2012), Bund. R., 2673-2682.

Montemurro, N., Postigo, C., Chirón, S., Barcelò, D. and Pérez, S. (2019). Analysis and fate of 14 relevant wastewater-derived organic pollutants in long-term exposed soil. Analytical and Bioanalytical Chemistry, (2019)41,1:2687-2696, https://doi.org/10.1007/s00216-019-01715-3.

Moral Pajares, E., Gallego Valero, L. and Román Sánchez, I. M. (2019). Cost of urban wastewater treatment and ecotaxes: Evidence from municipalities in southern Europe. Water, 11(3), 423.

Morales, I., Atoyan, A. J., Amador, A. J. and Boving, T. (2014). Transport of pathogen surrogates in soil treatment units: Numerical modeling. Water, ISSN:2073-4441, 2014, 6, 818-838; doi:10.3390/w6040818.

Morales, I. (2015). Modeling onsite wastewater treatment system contaminants in current and climate changing conditions. Kingston, University of Rhode Island, Doctor of Philosophy Thesis, Civil and Environmental Engineering, 2015.

Mortezaei, H. and Karimpour-Fard, M. (2017). Variation of the hydraulic conductivity of clayey soils in exposure to organic permeants. Civil Engineering Journal, Vol.3, No.11, November 2017, DOI:http://dx.doi.org/10.28991/cej-030936.

Mosavat, N. and Nalbantoglu, Z. (2011). Permeation of compacted clay with organic fluids. International Journal of Mining, Reclamation and Environment, 25:4, 313-320, DOI:10.1080/17480930.2011.608892.

Mtolera, I. and Dongli, S. (2018). Effect of effective microorganism and gypsum amendments on nutrient leaching, pH, electrical conductivity and Okra growth parameters under coastal saline soil. Communications in Soil Science and Plant Analysis, Vol:49, No:18, 2327-2337, DOI: 10.1080/00103624.2018.1499767.

Muhunthan, B. (1991). Liquid limit and surface area of clays. Geotechnique, 41(1), 135-138.

Murad, O. F. (2012). Obtaining chemical properties through soil electrical resistivity. Journal of Civil Engineering Research, 2(6), 120-128.

Murugaiyan, V. and Saravanane, R. (2009). Influence of pharmaceutical effluent on the physico-chemical behavior and geotechnical characteristics of clayey and silty soils. International Journal of Soil, Sediment and Water, Vol.2: Iss. 3, Article 4.

Mutamim, A. S. N., Noor, Z. Z., Hassan, A. A. M. and Olsson, G. (2012). Application of membrane bioreactor technology in treating high strength industrial wastewater: a performance review. Desalination, 305(2012), 1-11.

Nazir, K. A. (2011). Effect of motor oil contamination on geotechnical properties of over consolidated clay. Alexandria Engineering Journal, (2011)50, 331-335.

Neoh, H. C. Noor, Z. Z., Mutamim, A. S. N. and Lim, K. C. (2016). Green technology in wastewater treatment technologies: Integration of membrane bioreactor with various wastewater treatment systems. Chemical Engineering Journal, 283(2016), 582-594.

Nguetnkam, P. J., Kamga, R., Villiéras, F., Ekodeck, E. G., Razafitianamaharavo, A. and Yvon, J. (2011). Alteration of cameroonian clays under acid treatment. Comparison with industrial adsorbents. Applied Clay Science, 52(2011), 122-132.

Okur B., Yener H., Okur N. and İrget E. (2001). Monthly and seasonal variation of some pollution parameters of Büyük Menderes River. Pamukkale University, Journal of Engineering Sciences - PAJES, 7 (2): 243-250, (Turkish).

Oluremi, R. J., Adedokun, I. S., Olaoye, A., R. and Ajamu, O. S. (2012). Assessment of Cassava wastewater on the geotechnical properties of lateritic soil. The Pacific Journal of Science and Technology, Vol:13, Number:1, May2012, 631-639.

Önal, A. Ö., Demirbilek, D. and Demir, V. (2013). Geo-environmental site investigation for Tunceli, Turkey municipal solid waste disposal site. Engineering Geology, 159(2013), 76-82.

Oriola, F. O. P. and Saminu, A. (2012). Influence of textile effluent wastewater on compacted lateritic soil. The Electronic Journal of Geotechnical Engineering, 17, 167-177.

Ortega, M. L., Lebrun, R., Blais, J. F., Hausler, R. and Drogui, P. (2008). Effectiveness of soil washing, nanofiltration and electrochemical treatment for the recovery of metal ions coming from a contaminated soil. Water Research, 42(2008), 1943-1952.

Otis, R. J. and Anderson, D. J. (1994). Meeting public health and environmental goals: performance standards for onsite wastewater treatment systems. Proceedings of the Seventh National Symposium on Individual and Small Community Sewage Systems, 1-10.

Patterson, R. A. (1997). Domestic wastewater and the sodium factor. Site Characterization and Design of On-Site Septic Systems, ASTM STP 1324, M.S. Bedinger, A. I. Johnson, and J.S. Fleming, Eds., American Society for Testing and Materials, 1997, 23-35.

Phillips, J. P., Schubert, C., Argue, D., Fisher, I., Furlong, T. E., Foreman, W., Gray, J. and Chalmers, A. (2015). Concentrations of hormones, pharmaceuticals and other micropollutants in groundwater affected by septic systems in New England and NewYork. Science of the Total Environment, 512-513(2015), 43-54.

Phogat, V. K., Tomar, V. S. and Dahiya, R. I. T. A. (2015). Soil physical properties. Soil Science: an introduction. Indian Society of Soil Sciences, 135-171.

Pineda, A. J., Kelly, R., Bates, L., Sheng, D. and Sloan, S. (2013). Effects of pore fluid salinity on the shear strength of a soft clay. Conference Paper, July 2013, ResearchGate, DOI:10.1061/9780784412992.174.

Pistol Y. (1981). Determination of the presence of organic complexes in sewage water and their influence on soil hydraulic conductivity. M. Sc. Thesis, Fac. of Agriculture, Hebrew University of Jerusalem, Rehovot, 56.

Pitarch, E., Cervera, M. I., Portolés, T., Ibáñez, M., Barreda, M., Renau-Pruñonosa, A. and Hernández, F. (2016). Comprehensive monitoring of organic micro-pollutants in surface and groundwater in the surrounding of a solid-waste treatment plant of Castellón, Spain. Science of The Total Environment, 548, 211-220.

Pons, L. J. (1973). Outline of the genesis, characteristics, classification and improvement of acid sulphate soils. In Proceedings of the 1972 (Wageningen, Netherlands), International Acid Sulphate Soils Symposium, Vol.1, 3-27.

Prakash, S. and Arumairaj, D. P. (2015). Effects of acid and base contamination on geotechnical properties of clay. International Journal of Science and Research (IJSR), Vol.4, Issue 5, Paper ID:SUB154524, ISSN(Online):2319-7064, 1440-1444.

Pusch, R. and Schomburg, J. (1999). Impact of microstructure on the hydraulic conductivity of undisturbed and artificially prepared smectitic clay. Engineering Geology, 54(1-2), 167-172.

Qabany, A. A., Soga, K. and Santamarina, C. (2012). Factors affecting efficiency of microbially induced calcite precipitation. Journal of Geotechnical and Geoenvironmental Engineering, Vol.138, No.8, 992-1001.

Qin, W., Dou, J., Ding, A., Xie, E. and Zheng, L. (2014). A study of subsurface wastewater infiltration systems for distributed rural sewage treatment. Environmental Technology, 35(16), 2115-2121.

Qu, L., Li, Y., Kong, F., Zhao, L. and Sun, P. (2012). Problem and countermeasure of rural domestic sewage treatment. Agricultural Science & Technology, 13(2012), 2620-2622.

Ramya H. N., Umesha T. S. and Lalithamba H. S. (2018). Effect of calcium chloride on geotechnical properties of black cotton soil Ramya. Advances in Materials Science and Engineering, 2018, Vol:2, Issue:1, 1-7.

Ratnaweera, P. and Meegoda, N. J. (2006). Shear strength and stress-strain behavior of contaminated soils. Geotechnical Testing Journal, Vol. 29, No.2, DOI:10.1520/GTJ12686.

Reeve, R. C. and Tamaddoni, G. H. (1965). Effect of electrolyte concentration on laboratory permeability and field intake rate of a sodic soil. Soil Science, 99(4), 261-266.

Republic of Turkey, Legislation Information System, e-Legislation. Water Pollution Control Regulation, Legislation No: 7221, Official Gazette Date: 31.12.2004, Official Gazette Number: 25687, https://www.mevzuat.gov.tr/.

Republic of Turkey, Legislation Information System, e-Legislation. Ministry of Environment and Forestry, Wastewater Treatment Plants Technical Procedures Communiqué, Legislation No: 13873, Official Gazette Date: 20.03.2010, Official Gazette Number: 27527, https://www.mevzuat.gov.tr/.

Republic of Turkey, Legislation Information System, e-Legislation. Official Gazette Date: 30.11.2012, Official Gazette Number: 28483, From the Ministry of Forestry and Water Affairs: Surface Water Quality Regulation, https://www.mevzuat.gov.tr/.

Resmi, G., Thampi, G. S. and Chandrakaran, S. (2011). Impact of lead contamination on the engineering properties of clayey soil. Journal Geological Society of India, Vol.77, January 2011, 42-46.

Rice, R. C. (1974). Soil clogging during infiltration of secondary effluent. J. Water Pollut. Control Fed. 46:708-716.

Richards, L. A. (Ed.) (1954). Diagnosis and improvement of saline and alkali soils, Agriculture Handbook No. 60, U.S. Department of Agriculture, Washington, D.C.

Richards, S., Paterson, E., Withers, A. J. P. and Stutter, M. (2016). Septic tank discharges as multi-pollutant hotspots in catchments. Science of the Total Environment, 542(2016), 854-863.

Rodgers, M., Mulqueen, J. and Healy, M.G. (2004). Surface clogging in an intermittent stratified sand filter. Soil Science Society of America Journal 68: 1827-1832. 10.2136/sssaj2004.1827.

Sadat-Noori, M. S., Ebrahimi, K. and Liaghat, M. A. (2013). Groundwater quality assessment using the water quality index and GIS in Saveh-Nobaran aquifer, Iran. Environ Earth Sci, DOI:10.1007/s12665-013-2770-8.

Saghebian, S. M., Sattari, M. T., Mirabbasi, R. and Pal, M. (2014). Ground water quality classification by decision tree method in Ardebil region, Iran. Arabian journal of geosciences, 7(11), 4767-4777.

Şahin, Ü., Tunç, T. and Örs, S. (2011). Reuse wastewater in term of groundwater pollution. TABAD, Yuzuncu Yıl University Journal of Agricultural Sciences, 4(1), 33-39, ISSN:1308-3945, (Turkish).

Samsunlu, A. (2011). Environmental engineering chemistry, Birsen Publisher, Code No: Y.0029, Updated Edition, Istanbul, (Turkish).

Sanches, M. G., Magalhães, P. S. G., Remacre, Z. A. and Franco, H. C. J. (2018). Potential of apparent soil electrical conductivity to describe the soil pH and improve lime application in a clayey soil. Soil & Tillage Research, 175(2018), 217-225.

Sarah, P. (2004). Soil sodium and potassium adsorption ratio along a Mediterranean arid transect. J. Arid Environ. 59, 731e741.

Sawhney, B. L. and Hill, D. E. (1975) Phosphate sorption characteristics of soils treated with domestic wastewater. J. Environ. Qual., 4 (3), 342-346.

Scott, K. and Hughes, R. (Ed.) (1996). Industrial membrane separation technology. Springer Science & Business Media.

Shackelford, C. D. (2013). Membrane behavior in engineered bentonite-based containment barriers: State of the art. Coupled Phenomena in Environmental Geotechnics, 2013 Taylor & Francis Group, London, ISBN:978 1 138 00060 5, 45-60.

Shackelford, C. D. (2014). The ISSMGE Kerry Rowe Lecture: The role of diffusion in environmental geotechnics. NCR Research Press, Can. Geotech. J., 51(2014), 1219-1242, DOI:org/10.1139/cgj-2013-0277.

Shah, D. L. and Shroff, A. V. (1998). Effects of effluents of industrial waste on soil properties (A case study of Nandesari Area, Vadodara). Fourth International Conference on Case Histories in Geotechnical Engineering, Paper No:I0.08, 1059-1062.

Sharma, A. and Ramkrishnan, R. (2016). Study on effect of microbial induced calcite precipitates on strength of fine grained soils. Perspectives in Science, 8(2016), 198-202.

Shen, Y. L. and Wang, B. Z. (1999). New theory and application on biological sewage treatment. Chinese Environmental Science Press, Beijing, 1999, 547-586.

Singh, K. S., Srivastava, K. R. and John, S. (2008). Settlement characteristics of clayey soils contaminated with petroleum hydrocarbons. Soil & Sediment Contamination, 17(2008):290-300, DOI:10.1080/15320380802007028.

Sivakumar, D., Pavithra, S. L., Vasuki, K. and Lavanya, B. (2015). Groundwater suitability for irrigation around perungalathur, Chennai, Tamil Nadu. International Journal of Applied Engineering Research, 10(53), 2015.

Sivapullaiah, P. V. and Sridharan, A. (1985). Liquid limit of soil mixtures. Geotechnical Testing Journal, 8(3), 111-116.

Sivapullaiah, P. V., Kantha, L. H. and Kiran, M. K. (2003). Geotechnical properties of stabilised Indian red earth. Geotechnical and Geological Engineering, 21(2003):399-413.

Sivapullaiah, P. V. and Manju, M. (2005). Kaolinite-Alkali interaction and effects on basic properties. Geotechnical and Geological Engineering, 23(5):601-614, DOI:10.1007/s10706-004-1661-x.

Sivapullaiah, P. V. (2009). Effects of soil pollution on geotechnical behaviour of soils. IGC 2009, Guntur, 933-940.

Soellner, I. A. (2002). Transformation of organic matter during reclamation of wastewater by soil aquifer treatment and membranes. Arizona State University, Doctor of Philosophy Thesis, August 2002.

Sou/Dakouré, Y. M., Mermoud, A., Yacouba, H. and Boivin, P. (2013). Impacts of irrigation with industrial treated wastewater on soil properties. Geoderma, 200-201(2013), 31-39.

Sridharan, A., Nagaraj, S. T. and Sivapullaiah, V. P. (1981). Heaving of soil due to acid contamination. Proc. X Int. Conf. Soil Mechanics and Fdn. Engg. Stockholm, Balkema, 2, 383-386.

Sridharan, A. (1991). Engineering behaviour of fine grained soils: A fundamental approach. Indian Geotechnical Journal, 21(2), 133-144.

Sridharan, A. and Nagaraj, H. (2005). Plastic limit and compaction characteristics of fine grained soils. Proceedings of the Institution of Civil Engineers - Ground Improvement, 9(1), 17-22.

Sridharan, A. (2014). Fourth IGS-Ferroco Terzaghi Oration: 2014: Soil clay mineralogy and physico-chemical mechanisms governing the fine-grained soil behaviour. Indian Geotechnical Journal, 44(4), 371-399.

Stalin, V. K., Muthukumaran, K. and Kartikeyan, A. (2010). Effect of liquid waste on the index and engineering behaviour of soils. In Proceedings of the Indian Geotechnical Conference: IGC-2000: The millennium conference, Mumbai, Indian (pp. 13-15).

Stark, T. D., Jafari, N. H., Leopold, A. L. and Brandon, T. L. (2014). Soil compressibility in transient unsaturated seepage analyses. Canadian Geotechnical Journal, 51(8), 858-868.

Stawinski, J., Wierzchos, J. and Garcia-Gonzalez, T. M. (1990). Influence of calcium and sodium concentration on the microstructure of bentonite and kaolin. Clays and Clay Minerals, Vol.38, No.6, 617-622.

Stephenson, R. W., Dempsey, B. A. and Heagler, J. B. (1989). Chemically induced foundation heave. Foundation Engineering: Current Principles and Practices, ASCE, Geotechnical Engineering Div, New York, 633-642.

Stern, T. R. and Shackelford, D. C. (1998). Permeation of sand-processed clay mixtures with calcium chloride solutions. Journal of Geotechnical and Geoenvironmental Engineering, (1998)231-241.

Suarez, L. D. and Gonzalez-Rubio, A. (2017). Effects of the dissolved organic carbon of treated municipal wastewater on soil infiltration as related to sodium adsorption ratio and pH. Soil Science Society of America Journal, (2017)81:602-611, DOI:10.2136/sssaj2016.09.0310.

Tabatabaei, H. S., Mousavi, M. S., Mirlatifi, M. S., Sharifnia, S. R. and Pessarakli, M. (2017). Effects of municipal wastewater on soil chemical properties in cultivating turfgrass using subsurface drip irrigation. Journal of Plant Nutrition, Vol.40, No. 8, 1133-1142.

Tahtouh, J., Mohtar, R., Assi, A., Schwab, P., Jantrania, A., Deng, Y. and Munster, C. (2019). Impact of brackish groundwater and treatedwastewater on soil chemical and mineralogical properties. Science of the Total Environment, 647(2019), 99-109.

Talukdar, K. D. (2014). Behaviour of crude oil contaminated clayey sands. International Journal of Emerging Technology and Advanced Engineering, Vol.4, Issue 7, ISSN:2250-2459.

Tammemäe, O. and Torn, H. (2006). Environmental geotechnics in the service of sustainable development on the example of North-East Estonia-Sillamäe. Oil Shale, Estonian Academy Publishers, (2006), Vol.23, No.2, 177-186.

Tang, X., Xue, Z., Yang, Q., Li, T. and VanSeveren, M. (2017). Water content and shear strength evaluation of marine soil after electro-osmosis experiments. Drying Technology, Vol:35, No:14, 1696-1710, DOI:10.1080/07373937.2016.1270299.

Temizel, E. K. and Tok, S. (2019). Effects of irrigation water with different sodium adsorption ratio values on some soil properties. Journal of the Institute of Science and Technology, 9(3): 1729-1736, 2019.

Tengborg, P. and Sturk, R. (2016). Development of the use of underground space in Sweden. Tunnelling and Underground Space Technology, 55(2016), 339-341.

Terzaghi, K., Peck, R. B. and Mesri, G. (1996). Soil mechanics in engineering practice (3rd ed). New York: Wiley. ISBN: 978-0-471-08658-1.

Thakur, S. K. V., Sreedeep, S. and Singh, N. D. (2005). Parameters affecting soil-water characteristic curves of fine-grained soils. Journal of Geotechnical and Geoenvironmental Engineering, DOI:10.1061/(ASCE)1090-0241(2005)131:4(521).

Thomas, J. F., Gomboso, J., Oliver, J. E. and Ritchie, V. A. (1997). Wastewater re-use stormwater management and the national water reform agenda. Research Position Paper 1, CSIRO Land and Water, 1997, Australia, ISSN:1329-5713, ISBN:0-643-06050-2.

Thomas, M. (2009). Decentralized wastewater treatment design methodology. The University of Texas at San Antonio, Doctor of Philosophy Thesis, Department of Civil and Environmental Engineering, August 2009.

Todt, D., Jenssen, P. D., Klemenčič, A. K., Oarga, A. and Bulc, T. G. (2014). Removal of particles in organic filters in experimental treatment systems for domestic wastewater and black water. Journal of Environmental Science and Health, Part A, 49(8), 948-954.

Tonon, D., Tonetti, A. L., Coraucci Filho, B. and Bueno, D. A. C. (2015). Wastewater treatment by anaerobic filter and sand filter: Hydraulic loading rates for removing organic matter, phosphorus, pathogens and nitrogen in tropical countries. Ecological Engineering, 82, 583-589.

Tölgyessy, J. (Ed.). (1993). Chemistry and biology of water, air and soil: Environmental Aspects. Elsevier.

Treese, D. P., Clark, S. E. and Baker, K. H. (2012). Nutrient release from disturbance of infiltration system soils during construction. Advances in Civil Engineering, Volume 2012, ID393164, DOI:10.1155/2012/393164.

Ucun Özel, H. and Gemici, B. T. (2016). Determination of Bartın river pollution using the physical parameters. The Journal of Graduate School of Natural and Applied Sciences of Mehmet Akif Ersoy University, 7(1), 52-58, (Turkish).

Umar, M., Kassim, K. A. and Chiet, K. T. P. (2016). Biological process of soil improvement in civil engineering: A review. Journal of Rock Mechanics and Geotechnical Engineering, 8(5), 767-774.

Umesha, T. S., Dinesh, S. V. and Sivapullaiah, P. V. (2012). Effects of acids on geotechnical properties of black cotton soil. International Journal of Geology, 3(6), 69-76.

U.S. EPA. (2002). Onsite Wastewater Treatment Systems Manual. Office of Water, Office of Research and Development, U.S. Environmental Protection Agency, EPA/625/R-00/008 February 2002.

Vähäaho, I. (2016). An introduction to the development for urban underground space in Helsinki. Tunnelling and Underground Space Technology, 55(2016), 324-328.

Vandevivere, P. and Baveye, P. (1992). Saturated hydraulic conductivity reduction caused by aerobic bacteria in sand columns. Soil Science Society of America Journal, Vol:56(1):1-13.

Von Felde, K. and Kunst, S. (1997). N-and COD-removal in vertical-flow systems. Water Science and Technology, 35(5), 79-85.

Wang, D., Gerba, C. P. and Lance, J. C. (1981). Effect of soil permeability on virus removal through soil columns. Applied and Environmental Microbiology, Vol: 42, No:1, July 1981, Pp.83-88.

Wang, X. H., Zhang, Y. and Huang, C. H. (2014). Experimental study on the treatment of sewage by soil. In Applied Mechanics and Materials, Trans Tech. Publications, Vol. 464, 179-183.

Wang, Y., Yan, L., Li, J., Shen, H., Zhang, C. and Qu, T. (2016). A review of technology for small sewage treatment: The Chinese perspective. Oxidation Communications, 39, No.1-I, 275-284, 2016.

Wang, Y., Hu, X. and Zhang, L. (2017). Research on rural water pollution control based on game theory. 2nd International Conference on Education, Management and Systems Engineering (EMSE2017), ISBN:978-1-60595-466-0.

Wang, Y., Ma, F., Zhang, Q., Peng, C., Wu, B., Li, F. and Gu, Q. (2017). An evaluation of different soil washing solutions for remediating arsenic-contaminated soils. Chemosphere, 173(2017), 368-372.

Wang, Y., Soga, K., Dejong, J. T. and Kabla, A. J. (2019). A microfluidic chip and its use in characterising the particle-scale behaviour of microbial-induced calcium carbonate precipitation (MICP). Géotechnique, 69(12), 1086-1094.

Wang, Y. H., Han, Z. M. and Wang, Z. C. (2016). Research on different irrigation water effect on soda alkaline soil and horizontal drainage water salinity-alkalinity. Chemical Engineering Transactions, 55, 415-420.

Warkentin, B. P. (1961). Interpretation of the upper plastic limit of clays. Nature, 190(4772), 287-288.

Wen-zhi, Z., Jie-sheng, H., Jing-wei, W., Chi, X. and Mou-song, M. (2013). The impact of different fertigation practices and initial soil salinity on soil N and salinity transport. Research Journal of Applied Sciences, Engineering and Technology, 5(15): 3996-4005, ISSN:2040-7459; e-ISSN: 2040-7467.

Whiffin, S. V., Paassen, A. L. and Harkes, P. M. (2007). Microbial carbonate precipitation as a soil improvement technique. Geomicrobiology Journal, 24(2007):417-423, DOI:10.1080/01490450701436505.

Wu, C., Wu, X., Qian, C. and Zhu, G. (2018). Hydrogeochemistry and groundwater quality assessment of high flüoride levels in the Yanchi endorheic region, Northwest China. Applied Geochemistry, 98(2018), 404-417.

XiaoZhao, L., Congcong, L., Aurèle, P., Wenbo, W., HuanQing, L., Liping, S. and Chao, L. (2016). Multiple resources and their sustainable development in urban underground space. Tunnelling and Underground Space Technology, 55(2016), 59-66.

Xu, S., Gao, B. and Saiers, J. E. (2006). Straining of colloidal particles in saturated porous media. Water Resources Research, 42(12).

Yalvaç, E. (2011). Effect of wastewater on engineering properties of clay. Master Thesis, Civil Engineering Department, SDU Institute of Science, (Turkish).

Yang, Y., Zhan, X., Wu, S., Kang, M., Guo, J. and Chen, F. (2016). Effect of hydraulic loading rate on pollutant removal efficiency in subsurface infiltration system under intermittent operation and micro-power aeration. Bioresource Technology, 205, 174-182.

Yang, Y., Toor, S. G., Wilson, C. P. and Williams, F. C. (2017). Micropollutants in groundwater from septic systems: Transformations, transport mechanisms, and human health risk assessment. Water Research, 123(2017), 258-267.

Yesiller, N., Hanson, J. L., Cox, J. T. and Noce, D. E. (2014). Determination of specific gravity of municipal solid waste. Waste Management, 34(5), 848-858.

Yi, Q., Xianghua, W. and Xia, H. (2007). Development and application of some renovated Technologies for municipal wastewater treatment in China. Front. Environ. Sci. Engin. China (2007), 1(1): 1-12, DOI:10.1007/s11783-007-0001-9.

Yıldırım, N., Gürtuğ, Y. and Sesal, C. (2016). Microbial calcium carbonate formation mechanisms and application areas. Marmara Journal of Pure and Applied Sciences, 2(2016):70-80, DOI:10.7240/mufbed.73209, (Turkish).

Yılmaz, G., Yetimoglu, T. and Arasan, S. (2008). Hydraulic conductivity of compacted clay liners permeated with inorganic salt solutions. Waste Management & Research, 26(5), 464-473.

Zbik, S. M., Williams, J. D., Song, F. Y. and Wang, C. C. (2015). Smectite clay microstructural behaviour on the Atterberg limits transition. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 467(2015), 89-96.

Zhan, J. X., Zhi, C. Y. and Xia, P. H. (2010). Research status and countermeasures of new sewage treatment technology in rural area. Journal of Anhui Agricultural Sciences, 2010, 38(22):11941-11942.

Zhang, T. C. and Shan, J. (1999). In situ septic tank effluent denitrification using a sulfur- limestone process. Water Environment Research, 71(7), 1283-1291.

Zhang, J., Huang, X., Liu, C., Shi, H. and Hu, H. (2005). Nitrogen removal enhanced by intermittent operation in a subsurface wastewater infiltration system. Ecological Engineering, 25(4), 419-428.

Zhang, Z., Lei, Z., Zhang, Z., Sugiura, N., Xu, X. and Yin, D. (2007). Organics removal of combined wastewater through shallow soil infiltration treatment: A field and laboratory study. Journal of Hazardous Materials, 149(2007), 657-665.

Zheng, P., Cui, J., Hu, L., Chen, P., Huang, J., Cheng, S. and Mu, K. (2016). Effect of long-term operation of a subsurface wastewater infiltration system (SWIS) based on the limiting value of environmental carrying capacity. Ecological Engineering, 92, 190-198.

Zhou, Bo., Wang, Di., Wang, T. and Li, Y. (2018). Chemical clogging behavior in drip irrigation systems using reclaimed water. Transactions of the ASABE,61. 1667-1675. 10.13031/trans.12902.

APPENDICES

Appendix A. GASKI Kızılhisar Wastewater Plant Permit Letter.

Arıtma Tesisleri Dairesi Başkanlığı
Sayı: 97123044-906-E.2017-1598/14167
Tarih: 11.10.2017
Dosya Numarası: 2017-36939

GASKİ

T.C.
GAZİANTEP BÜYÜKŞEHİR BELEDİYESİ
GASKİ GENEL MÜDÜRLÜĞÜ
Arıtma Tesisleri Daire Başkanlığı

K - Q TSE-ISO-EN 9000

Sayı : 97123044-906-E.2017-1598/14167 11.10.2017
Konu : Öğrenciler Hk.

HASAN KALYONCU ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜNE
Yeşilkent Mahallesi, Havaalanı Yolu Üzeri 8 Km., 27410
Şahinbey/GAZİANTEP

İlgi : 27.09.2017 tarihli 129 sayılı yazınız

İlgi yazıda; Genel Müdürlüğümüze bağlı Kızılhisar İleri Biyolojik Atıksu Arıtma Tesisimizde, doktora ve yüksek lisans çalışmalarında öğrencilerinize izinlerin verilmesi ve gerekli yardımların yapılması talep edilmiştir.

Konu ile ilgili çalışmalara yönelik gerekli izin ve yardımların yapılacağı tarafımızca uygun görülmüştür.

Bilgilerinize rica ederim.

Hüseyin SÖNMEZLER
Genel Müdür

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Bilgi için: ERDİNÇ EKMEKÇİOĞLU İşçi
Sayfa 1 / 1

Bu belge, güvenli elektronik imza ile imzalanmıştır.
http://ebelge.gaski.gov.tr adresinden Doğrulama Kodu : 768678A2 Belge No: 97123044-906-E.2017-1598/14167 ile doğrulayabilirsiniz.

Appendix B. Wastewater elemental analysis results.

Soil Type	Ca (mg/L)				Mg (mg/L)				Na (mg/L)				K (mg/L)			
	Influent	9 L/day	18 L/day	36 L/day	Influent	9 L/day	18 L/day	36 L/day	Influent	9 L/day	18 L/day	36 L/day	Influent	9 L/day	18 L/day	36 L/day
ADIYAMAN	64,44	192,60	236,60	56,00	18,17	30,40	16,10	13,15	34,86	111,20	0	42,36	103,50	22,90	0	33,00
	58,08	128,00	162,30	132,20	17,18	20,02	22,90	26,90	42,80	139,90	2,965	114,40	10,85	0	0	63,02
	99,18	154,60	228,20	114,08	20,04	25,12	30,69	37,16	108,20	186,18	32,16	256,14	21,16	0	0	140,10
	165,20	176,40	92,04	94,98	34,16	31,18	28,36	32,66	64,00	276,40	190,50	218,60	82,19	36,91	102,50	124,24
	67,18	217,20	103,16	94,12	26,69	40,08	31,14	34,88	164,66	396,20	218,00	233,20	100,90	40,96	84,04	131,10
GAZİANTEP	105,90	99,08	87,88	112,60	16,88	5,689	6,017	7,227	42,76	3,327	7,957	10,78	16,30	26,09	2,877	1,755
	78,14	72,78	102,00	102,60	14,81	7,517	6,851	8,485	36,73	0	3,422	24,10	13,17	0	0	0
	76,86	74,16	99,81	121,90	17,84	4,665	7,297	9,409	83,47	0	4,845	27,50	11,45	0	0	0
	84,49	97,99	98,97	77,17	18,06	5,703	7,130	7,408	40,52	0	5,755	29,63	17,64	0	0	19,99
	107,30	81,38	72,35	93,85	19,34	7,705	10,98	8,171	66,14	0	23,63	31,29	14,64	0	5,954	0
KİLİS	78,95	81,34	156,10	80,54	26,33	25,15	19,39	21,23	107,50	133,30	26,27	39,84	53,48	51,67	9,056	14,41
	91,24	400,30	133,20	142,50	27,18	45,06	11,68	12,92	92,31	57,79	28,59	20,26	15,51	19,98	0	0
	86,46	205,20	62,89	107,20	26,04	16,87	9,774	10,48	48,25	20,54	39,89	18,88	16,67	1,781	0	0
	89,81	335,40	22,12	80,82	27,35	28,29	10,66	9,949	97,14	46,24	55,56	23,96	15,57	5,219	0,095	0
	75,21	132,70	66,25	82,46	26,93	12,23	14,29	10,79	61,24	8,467	53,38	29,89	21,28	0,197	0,675	0
ŞANLIURFA	272,20	310,80	245,20	91,42	41,66	50,60	47,84	25,96	47,32	72,76	71,00	88,74	154,22	9,446	9,424	17,348
	95,76	116,22	123,22	274,40	25,42	22,38	24,44	28,98	32,08	9,544	21,68	39,66	8,234	0	0	1,474
	80,00	87,20	77,92	80,92	24,33	19,588	14,982	22,38	68,22	18,886	4,236	20,28	10,244	0	0	0
	143,86	95,18	70,40	86,24	31,62	19,768	14,692	26,52	75,12	14,478	17,34	67,64	11,374	0	0	8,858
	86,24	117,46	76,86	79,24	29,92	27,40	19,992	20,84	221,80	35,36	34,04	25,98	116,4	0	1,374	6,418