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Virus removal from treated wastewater in modified garden soil columns, Kuwait

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ABSTRACT

A research study was conducted to determine the addition of garden soil to natural soil for removal of coliphage viruses from treated wastewater. Treated wastewater containing viruses was passed through soil columns filled with soil collected from Sulaibiya area, Kuwait. The four soil column experiments were under operation for eight months. The first and second soil columns filled with natural soil, while the third and fourth soil columns filled with modified soil consist of Sulaibiya soil mixed with 1% garden soil. All soil columns had soil depth of 0.1 m and with constant hydraulic head of 0.1 m above soil surface. For each experimental condition, two identical columns were set up, so that the reproducibility of the results can be evaluated, producing four columns. For all columns, the tests were conducted under alternating 1 d flooding and 1 d drying conditions. Influent and effluent water samples were collected and analysed following cycles of flooding periods. The coliphage virus counts in the treated wastewater ranged between 0 and 62,800 pfu/100 ml. The laboratory results revealed that coliphage removal for Sulaibiya soil ranged between 58% and 100% with average value of 88.4%, while their removal efficiency for modified columns was between 60% and 100% with average value of 92.3%. The presence of garden soil mixed with the soil relatively increased the coliphage removal from treated wastewater.

Keywords: Coliphage viruses, Treated wastewater, Soil column experiments, Effluent

1. Introduction

Kuwait is a modern industrialized nation that meets most of its domestic, commercial and industrial water needs by desalination of seawater. However, while desalination technologies demonstrated a remarkable progress in recent years, they still do not present a viable economical option for wide agricultural use. Therefore, countries with limited water resources carry on research effort into agricultural use of wastewater since recycling of renovated wastewater generates a valuable water resource.

As Shahalam et al., (2017) points out, Kuwait produces 1 million m^3 of tertiary treated wastewater per year, of which only 40% is used for irrigation, while the remainder is being discharged to the Arabian Gulf. The volume of tertiary treated wastewater is set to increase in line with growing population and escalating water needs. In this context, the methods that can restore the wastewater quality to usable levels will be gaining and ever increasing importance.

Water for agriculture needs to meet stringent quality criteria, which include absence of pathogens like virus and bacteria, and low nitrogen levels (Elkayam et al., 2018). These parameters are difficult to achieve within economic realms of existing purification technologies. Therefore, researchers concentrate on efficient ways of improving the quality of wastewater using natural environments, for example soil.

Coliphage viruses (i.e. viruses that uses *Escherichia coli* bacteria cells as host) were selected for this study because their structure, composition, morphology and size closely resemble that of enteric viruses, they are easily grown on bacteria cultures, and only simple materials and equipment are needed for coliphage detection and quantification by plaque

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forming units (pfu), (APHA, 2005). Also, coliphage viruses are chlorine resistant microorganisms and considered as indicators for wastewater viruses.

Soil aquifer treatment (SAT) technique is an economically attractive method for the treatment of wastewater for restricted and unrestricted irrigation (Shahalam et al., 2017). These systems are operated to use underground formations as a treatment facility, and thus are called SAT or geo-purification systems. While significant research effort has been applied to SAT throughout the world, there is an evident need to test this technique with local Kuwaiti soils, wastewater, and climatic conditions. A laboratory study concentrated on the tertiary treated wastewater from the Sulaibiya wastewater treatment plant, treated by sandy soils from Kuwait.

Adsorption appears to be the predominant factor in virus removal by soil (Yanji et al., 2001; Park et al., 2016). Thus, factors influencing adsorption phenomena will determine not only the efficiency of short-term virus retentions, but also the long-term behavior of viruses in the soil. Such factors include soil composition, and the presence of soluble organic matter. Viruses are readily adsorbed to clays under appropriate conditions, and the higher clay contents of the soil, the greater the expected removal of viruses (Al-Haddad et al., 2018). Sandy loam soils and other soils containing organic matter are also favorable for virus removal. Soils with a low surface area do not achieve good virus removal (Kauppinen et al., 2018). Soluble organic matter competes with viruses for adsorption sites on the soil particles, resulting in the decreased virus adsorption. The objective of the study was to assess the removal of coliphage viruses from treated wastewater using natural soil and modified soil column experiments in Kuwait.

2. Methodology

2.1. Soil collection and properties

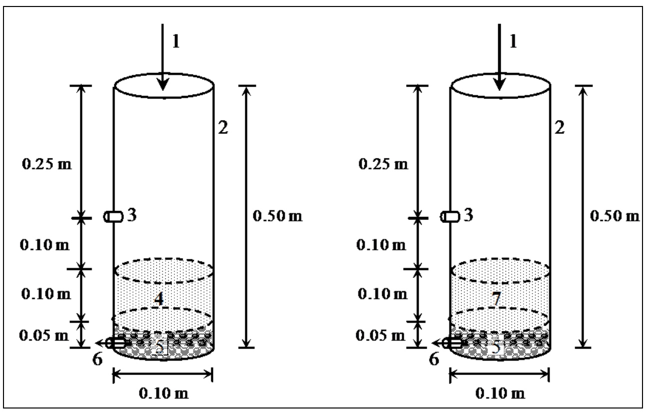
One type of soil that was used in column experiments included soil collected from Sulaibiya area, Kuwait. Soil samples from the top 10 cm from the Sulaibiya area were used to fill four soil columns. Each 5 cm of soil inside the column was compacted until filled the required total soil length and this compaction method will produce density (1.8 g/cm^3), specific gravity (SG) (2.63) similar to their values in the field. Modified soil was prepared by mixing 1.374 kg natural soil with 13.88 g (i.e., 1%) garden soil. Sample of this mixture was collected using sample divider to determine its properties and to confirm even distribution of 1% garden material in the soil. Bentonite clay was selected for this study because it mainly consists of organic content (more than 900.0 mg/kg-TOC) that have a reasonable specific surface area (SSA).

2.2. Design and column construction

Four soil columns were constructed to study removal of viruses from tertiary treated wastewater using different natural soil and mixed soil containing 1% clay. The columns were constructed using polyvinyl chloride (PVC) pipes of 0.1 m diameter. These columns were practical for water sampling in the laboratory, easy to fabricate, cheap and used in other researches (Al-Haddad et al., 2015) in the field of SAT system, and allowed to correlations of the results of this study with the work of the pervious researches under the similar laboratory conditions. The PVC pipes reduce contamination and interaction between coliphage and the column walls. The total length of 0.5 m contained 0.05 m of gravel, 0.1 m of natural soil, 0.1 m of constant wastewater head and allowed a margin of safety (Fig. 1). The depth of the natural soil was selected as the optimum depth for virus removal, following the practices of previous researchers (Al-Haddad et al., 2015). The gravel in this study was used as a filter zone to prevent the passing of fine materials through the outlet. The column numbers one and two were filled up with natural material and three and four were used for modified soil. The grain size distribution, SSA, total organic carbon content (TOC %), total carbonate content (CO_3 %), cation exchange capacity, density, SG, porosity (P) and fine materials (silt and clay) content of the soil were determined for both types of soils (natural and modified) using standard methods described by (Page et al. 1982).

2.3. Column operation and maintenance

The tertiary wastewater was pumped daily from the Sulaibiya Data Monitoring Center to a high level 1.89 m^3/L capacity tank through a PVC line. The tertiary wastewater was fed to all the soil columns simultaneously. The tertiary treated wastewater header tank, and all the feeding PVC lines were flushed and cleaned regularly during drying and maintenance periods of column operation. Constant head of 0.1 m of treated wastewater was used in measuring the removal of coliphages. These constant head was maintained for the soil columns by overflow outlets above the soil surface. For each experimental condition, two identical columns were set up, so that the variability of the results can be assessed. The coliphage tests were studied only under alternating flooding and drying conditions. All columns were subjected to short flooding and drying cycles of 1 d of flooding alternating with 1 d of drying for eight months. During the drying periods and at the end of each month, the maintenance of



1- Influent
2- PVC Column
3- Overflow Outlet
4- Soil
5- Gravel
6- Outlet for Sample Collection
7- Soil with Garden Soil Materials

Fig. 1. Design of soil column experiments.

the soil columns was carried out by scratching organic layer on top of soil surface using long plastic forks and removing this layer to increase the infiltration rate. The infiltration rate was measured for columns at the beginning of the flooding period, and calculated according to the following equation (Al-Haddad et al., 2015):

$$\text{Infiltration rate}\left(I\right)=\frac{V}{At} \quad (1)$$

where V is the volume of the outflow in time t and A is the cross-sectional area of the soil column. In this study, infiltration rate was expressed in m/d. In the field, the infiltration rates of the treated water through the aquifer will be affected by presence of impermeable layers such as silt, clay and carbonate layers beneath the wastewater recharge spreading basins.

2.4. Wastewater sampling and analysis

Samples of influent and effluent were collected 24 h after the flooding periods. Each sample was separated into two subsamples, and measurements of the coliphage content of each subsample were carried out to ensure the accuracy of the analyses. Samples were collected using sterile 100 ml glass bottles with glass stoppers, and they were analyzed within 4 h of collection. Any sample kept for 4 to 24 h was cooled to at least 10°C. Virus samples were analyzed in the laboratory of Water Research Center Laboratory (WRC) at Kuwait Institute for Scientific Research (KISR) using the standard methods for the examination of water and wastewater (APHA, 2005). Fresh bacteria and coliphage media were prepared at the end of each month. Modified tryptic soy agar (MTSA) media and *Escherichia coli* C (host culture, WARD'S No. 85W1662) were used for detection of coliphage viruses (APHA, 2005).

3. Results and discussion

The result of grain size distribution for Sulaibiya soil is plotted in Fig. 2. The *S*-shaped grain size graph indicates rather poorly sorted distributions spanning the gravel, sand, and fine classes. The soil tested consisted of sandy soils with different percentages of fines (i.e., silt and clay). Al-Haddad (2000) reported that Sulaibiya soil consists of 97.5% sand, 1.5% silt and 1% clay. The mean value of fines for the natural soil samples was 2.5% and that for modified soil was 3.10%. The amount of fines was found to be an important factor for the removal of virus by adsorption. The mean values of P, SSA and the TOC for natural soils were found to be 33%, 8.22 m^2/g, and 343.23 mg/kg, respectively. The same for the modified soils were 44%, 5.88 m^2/g, 5.88 m^2/g and 907.18 mg/kg for the modified soils. The mean value of carbonate content for both types of soil was 5.5%. Soils with high contents of fines, organics and carbonates are expected to adsorb more viruses from treated wastewater.

The soil columns were recharged with treated wastewater from August 2004 to February 2005. During the period August 2004–20 November 2004, tertiary treated wastewater was used for recharge. After this period, there was a change in the quality of water used for recharge due to the mixing of tertiary treated wastewater from Al-Jahra wastewater plant with reverse osmosis (RO) treated wastewater from Sulaibiya Plant Utility Company at Sulaibiya area(Al-Haddad et al., 2005). On 14 February 2005, only the RO treated wastewater was passing through the soil columns. The coliphage virus count in the treated wastewater ranged between 0 and 62,800 pfu/100 ml during the study. However, the coliphage counts decreased when the tertiary treated wastewater was mixed with RO treated wastewater, and coliphage counts fell to nil in the RO treated wastewater at the end of soil column experiments.

The effects of natural and modified soil types on coliphage virus removal from the treated wastewater are presented in Figs. 3–5. The coliphage counts in the treated wastewater after passing natural and modified soil ranged between 58 and 100 pfu/100 ml; and between 75 and 100 pfu/100 ml, respectively (Figs. 3 and 4). At the same time, the coliphage removal using Sulaibiya soil ranged between 58% and 100% with average value of 88.4%, while their removal efficiency using modified soil vary between 60% and 100% with average value of 92.3% (Fig. 5). This data support that idea that addition of organics in the soil increases

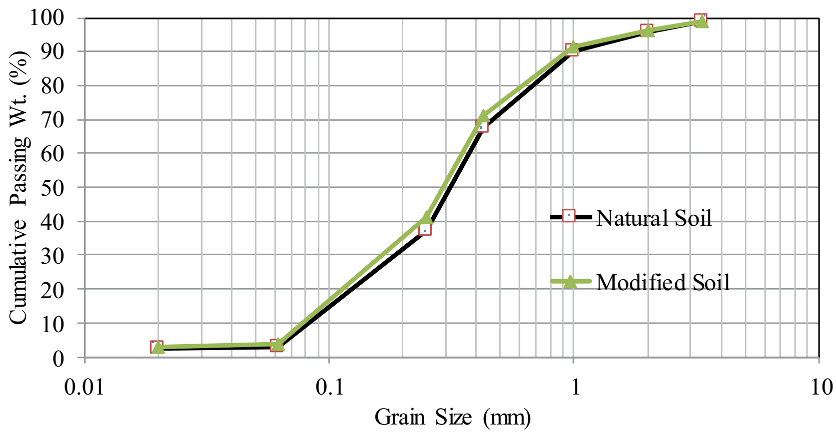


Fig. 2. Grain size distribution for natural and modified soils.

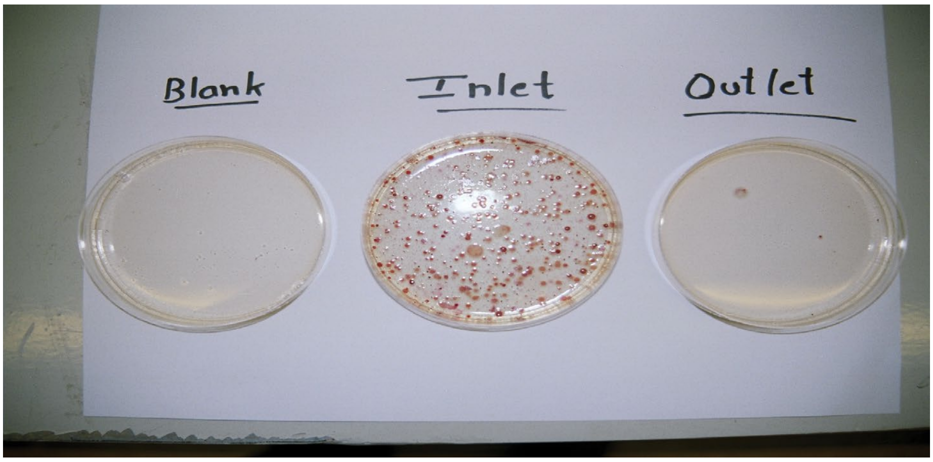


Fig. 3. Coliphage viruses before and after passing modified soil.

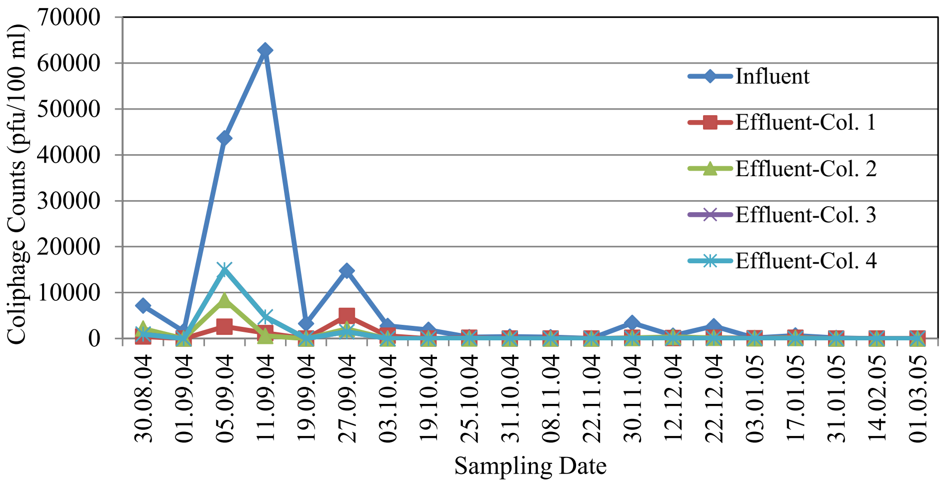


Fig. 4. Coliphage counts using natural soil (columns 1 and 2) and modified soil (columns 3 and 4).

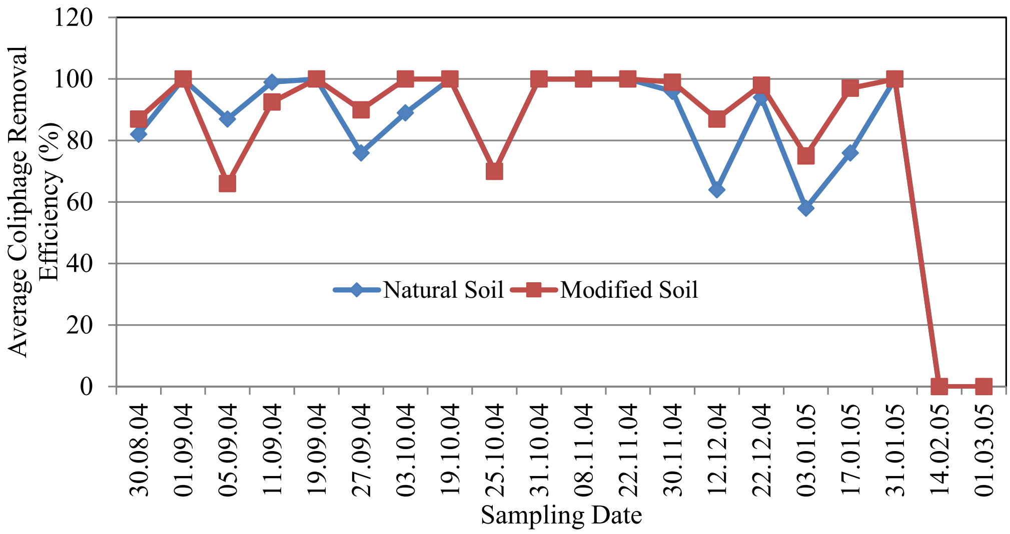


Fig. 5. Coliphage removal efficiency after passing natural and modified soil columns.

the coliphage removal from treated wastewater. A similar soil column experiment was carried out by Al-Haddad et al. (2018) where they reported that viruses were mostly adsorbed at the top 5 cm of soil. The results obtained in the present study confirm this conclusion. The infiltration rates for Sulaibiya natural soil ranged between 0.4–10.9 m/d with an average value of 2.3 m/d, while those rates for modified soil (soil with added organics) ranged between 0.2–8.9 m/d with an average value of 2.0 m/d. It is clear that infiltration rate was reduced due to addition of bentonite clay in the modified soil column. The reduction in the infiltration rates produced longer contact time between the viruses in the treated wastewater and the soil particles, which later reflected in high values of coliphage removal efficiency from treated wastewater.

4. Conclusions

Soil column experiments were carried out to determine removal of coliphage viruses from the treated wastewater using Sulaibiya natural soil and amended soil mixed with garden soil materials. Total of four soil columns were constructed at the KISR wastewater research building in the Sulaibiya area. Soil samples were collected to fill the columns and to determine their properties. All soil columns had soil depth of 0.1 m and with constant hydraulic head of 0.1 m above soil surface. The treated wastewater was pumped daily from the tank and fed to all the soil columns. All columns were subjected to short flooding and drying cycles of 1 d of flooding alternating with 1 d of drying for eight months. Samples of influent and effluent water were collected 24 h after the flooding periods.

High counts of coliphage viruses were found in the tertiary treated wastewater (62,800 pfu/100 ml) and their counts was reduced after mixing it with RO treated wastewater. The laboratory results revealed that coliphage removal for Sulaibiya soil ranged between 58% and 100% with average value of 88.4%, while their removal efficiency using modified soil was 60% and 100% with average value of 92.3%. The soil properties such as amount of fines, organics, and the infiltration rates were important factors that increased the coliphage removal from the treated wastewater. Based on the laboratory experiments, following recommendations are forwarded:

- Removal efficiency of bacteria and viruses (enteric viruses) from the wastewater using the SAT system should be determined in the field. The field study should be conducted over a period of several years and conclude with a detailed presentation of all expected benefits and shortcomings of SAT in terms of technical, environmental, social and economic returns. This study should also provide a set of detailed guidelines on use of SAT in Kuwait.
- Operation of SAT system should be applied separately for both the RO-treated wastewater, and tertiary treated wastewater to compare the bacteria and virus removal efficiency from both types of water.
- In agricultural areas, the treated wastewater should be passed through a filter zone of sandy soil mixed with 1% organics (organic fertilizer) before this water is used for irrigating the agricultural areas. In addition, this mixture of soil can be added at the base of surface spreading basins recharged by treated wastewater to remove the pathogen.

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References

Al-Haddad, A., (2000), Optimization of total nitrogen and total phosphate removal from tertiary wastewater by filtration through soil from Sulaibiya, Kuwait, Ph.D. Dissertation, University of Strathclyde, Glasgow, UK.

Al-Haddad, A., Al-Qallaf, H., Al-Salman, Naseeb, H., Bhandary, H., F. Marzouk, F., (2005), Enhancement of tertiary treated wastewater using soil aquifer treatment system in Kuwait, Kuwait Institute for Scientific Research, Report No. KISR7743, Kuwait.

Al-Haddad, A., Rashid, T., Al-Salman, B., (2015), Optimum soil depth for removal of coliphage viruses from treated wastewater, Kuwait, Desalination and Water Treatment, 53(10), pp. 2727–2731.

Al-Haddad, A., Rashid, T., Al-Salman, B., H. Naseeb, (2018), Coliphage Removal from Treated Wastewater in Modified Sand Columns, Kuwait, Twenty One International Water Technology Conference, 28–30 June 2118, Ismailia, Egypt.

APHA, (2005), Standard method for the examination of water and wastewater, American Public Health Association, Washington, D.C., USA.

Elkayam, R., Aharoni, A., Vaizel-Ohayon, D., Sued, O., Katz, Y., Negev, I., Marano, M., Cytryn, E., Shtrasler, L., Lev, O., (2018), Viral and microbial pathogens indicator microorganisms, microbial source tracking indicators and antibiotic resistance genes in a confined managed effluent recharge system, Journal of Environmental Engineering, 144(3), Article No. 05017011.

Kauppinen, A., Pitkanen, T., Miettinen, I.T., (2018), Persistent norovirus contamination of groundwater supplies in two waterborne outbreaks, Food and Environmental Virology, 10 (1), pp. 39–50.

Page, A., Miller, R., Keeney, D., (1982), Methods of Soil Analysis. Part 2-Chemical and Microbiological properties, Second Ed., Number 9 in the Agronomy series, American Society of Agronomy, Madison, Wisconsin, USA.

Park, E., Mancl, M., Tuovinen, H., Bisesi, S., Lee, J., (2016), Ensuring safe reuse of residential wastewater: reduction of microbes and genes using peat biofilter and batch chlorination in on-site treatment system, Journal of Applied Microbiology, 121 (6), pp. 1777–1788.

Shahalam, A.M., Ahmed, M.E., Al-Haddad, A., 2017, Wastewater resources in Kuwait: Effluent Quantity and reused demand, Published by Kuwait Institute for Scientific Research, Kuwait, p. 135.

Yanji, C., Yan, J., Markus, F., Marylynn, Y., (2001), Mechanisms of virus removal during transport in unsaturated porous media, Water Resources Research, 37(2), pp. 253–263.