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APPLICABILITY OF SOIL AQUIFER TREATMENT (SAT) IN KUWAIT

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Abstract:

This study aims to assess the long-term applicability of the soil-aquifer treatment (SAT) for the renovation of tertiary treated wastewater under the prevailing soil and meteorological conditions in Kuwait. An intensive drilling and sampling program was carried out to obtain data and information on the soil and groundwater characteristics in the study area and to install a permanent network of monitoring wells to observe the changes in groundwater quality with time. The groundwater characteristics were determined through in-situ field measurements and representative samples were collected from each of the penetrated zone intervals. Eleven ceramic cups were installed within the root zone at selected locations within the study area to collect infiltrating water and to monitor the changes in water quality with depth. Soil samples were collected from irrigated and non-irrigated areas and those were used to construct soil columns in the laboratory to determine the changes of the quality of the percolating irrigation water. Four lysimeters were also constructed on-site to measure the evapotranspiration rates from the soil surface within the study area.

الملخص

استهدفت هذه الدراسة تقييم إمكانية تطبيق تقنية المعالجة الطبيعية للمياه بالاستفادة من خصائص التربة في تحسين نوعية مياه الصرف المعالجة تحت الظروف السائدة في دولة الكويت على المدى الطويل. و قد تم خلال الدراسة تنفيذ برنامج ميداني مكثف لجمع المعلومات المتعلقة بالتربة و المياه الجوفية في منطقة الدراسة من خلال شبكة مكونة من ثماني آبار مراقبة. كما تم تحديد خصائص المياه الجوفية ميدانياً، و من ثم تم جمع عينات منها ضمن النطاقات المختلفة لمكمن المياه الجوفية. و تم كذلك تركيب 11 كوباً خزفية ضمن النطاق الجذري للنباتات في مواقع مختارة ضمن منطقة الدراسة لجمع مياه الري المتسربة عبر طبقات التربة و تحديد التغير الحاصل في نوعيتها مع ازدياد العمق. كما تم جمع عينات من التربة من المناطق المروية و غير المروية، و تمت الاستفادة منها في إنشاء أعمدة رملية للدراسات المخبرية لتحديد التغير الحاصل في نوعية مياه الري المتسربة عبر طبقات التربة. و تم كذلك تركيب أربعة أجهزة لقياس معدلات تسرب المياه و النتح بغرض دراسة هذه الظاهرة بشكل مفصل في منطقة الدراسة.

Introduction

Kuwait is situated in an arid region with extremely hot weather conditions, very little rainfall and scarce natural water resources. The annual average rainfall reaches about 120 mm, whereas the average evaporation rate varies from 3 to 16 mm/d. The Kuwait Group aquifer and the underlying Dammam Formation aquifer are the main components of the aquifer system of Kuwait. The groundwater of these two aquifers is generally saline to brackish, with the exception of the Al-Raudhatain area, which is located in the extreme northern part of the country, where fresh groundwater lenses occur.

As the sources for supply of freshwater are either becoming scarcer or getting polluted through human intervention, the reuse of municipal wastewater is becoming an important issue in a world of increasing demand for water for human consumption and agriculture. The matter has added urgency in the arid and semi-arid countries like Kuwait where the sources of fresh water are very limited. In Kuwait, as in the other countries bordering the Arabian Gulf, the desalination plants meet the bulk of the freshwater demand. With the rapidly rising demand for freshwater and the high cost for installation and maintenance of the desalination plants, the situation is getting more and more critical. On an average, 70-80% of the daily supply of freshwater to households converts to wastewater. The treated wastewater can, therefore, be an important source of useable water, especially for agriculture. The infiltrating return water may improve in quality as it interacts with the soil through which it passes. Many of the dissolved chemical components, both organic and inorganic, may be either adsorbed on the mineral grain surfaces or precipitated through chemical interaction and thus removed from the infiltrating water. The bacteria and viruses may also either die off or get attached to the mineral grains. The extents of these removals, however, vary from soil to soil and depend on the mineralogy of the soil, climatic conditions, microbiology of the soil, the loading rate of the water, and the length of the wetting and drying cycles. Lack of exact knowledge about the degree of improvement in quality that may be achieved through the natural treatment of wastewater by the local soil under the prevailing climatic conditions and the concerns about health effects of the use of this water are, however, thwarting the development of the full potential of this source.

The Study Area

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The study area is located northwest of Kuwait City. It can be considered as a full-scale field laboratory to study the long-term effects of irrigation with treated wastewater and the applicability of natural soil treatment of infiltrating water under the conditions of Kuwait. The effects on groundwater quality, soil chemistry, hydraulic conductivity, plant growth, crop productivity and the concentration of various trace and minor elements in the agricultural produce of the farm, under the soil and climatic conditions of an arid environment can be studied in this farm. The study focuses on the changes in quality of irrigation water as it infiltrates through the soil and its effects on the hydraulic parameters.

Soil Aquifer Treatment (SAT)

The degree of success of natural soil treatment is site specific, dependent on the lithology and the hydrological characteristics of the unsaturated zone and the aquifer, the depth to the groundwater table, the local climate, and recharge water quality. The information gathered from the study area is of special significance to the long-term applicability of the natural soil treatment of wastewater in Kuwait. The study attains added importance as plans are under way to supply the farming areas in Kuwait with treated wastewater for irrigation purposes.

Field Investigations

Construction and Installation of Ceramic Cups

Eleven ceramic cups were installed at three locations within the study area to collect infiltrating water and to monitor the changes in water quality with depth (Plates 1 and 2). The ceramic cups were installed at depths 30, 60, 90, and 120 cm below the ground surface (Plate 3).

Plate 1. Ceramic Cups of Different Lengths Installed in the Study Area.

Plate 2. Drilling holes for ceramic cups installation.

Plate 3. Installation of Ceramic Cups.

Construction and Installation of Lysimeters.

A Lysimeter is an instrument that is used to measure the percolation and evapotranspiration rates from the soil. The instrument facilitates isolating and measuring separately the four components of the water budget on a control volume of soil sample. These components are rainfall, evapotranspiration, added water, and percolated water; they are related to each other through the following mass balance equation:

$$\text{Evapotranspiration (ET)} = \text{Rainfall (R)} + \text{Added water (A)} - \text{Percolated water (P)}$$

If water at the plant's root is not a limiting factor, then the evapotranspiration measurement reflects the potential evapotranspiration (PE). In this case PE is controlled by weather, e.g. ambient temperature, and is independent of the amount of vegetation.

Four lysimeters were constructed and installed in selected locations within the study area. The constructed lysimeter (Fig. 1) is composed of a cylinder (30 cm diameter and 25 cm deep) and a receiving vessel (30 cm diameter and 42 cm deep). The receiver is covered at all times (except during measurements), is deeper than the tank and is capable of holding the largest volume of water (either from rainfall or from irrigation water) at the site; less than 20 cm. Another container of 5.5 litre capacity forms a large collecting vessel within the buried receiver tank. A gravel (2-3 mm) layer overlain by a thin sand layer is placed under the cut and relocated soil section. This gravel layer allows filtering of the percolated water. The lysimeter tank is connected to the receiver tank by a small diameter pipe. A water gauge is also placed near the lysimeter to record the volume of water.

A small amount of water (about a liter) is sprinkled every day to the lysimeter, where about 50 to 100 mls are allowed to percolate. The percolating water P is measured in mls at the same time as the application of irrigation water. The amount necessary to maintain that percolation water amount is dependent on the time of year and weather conditions.

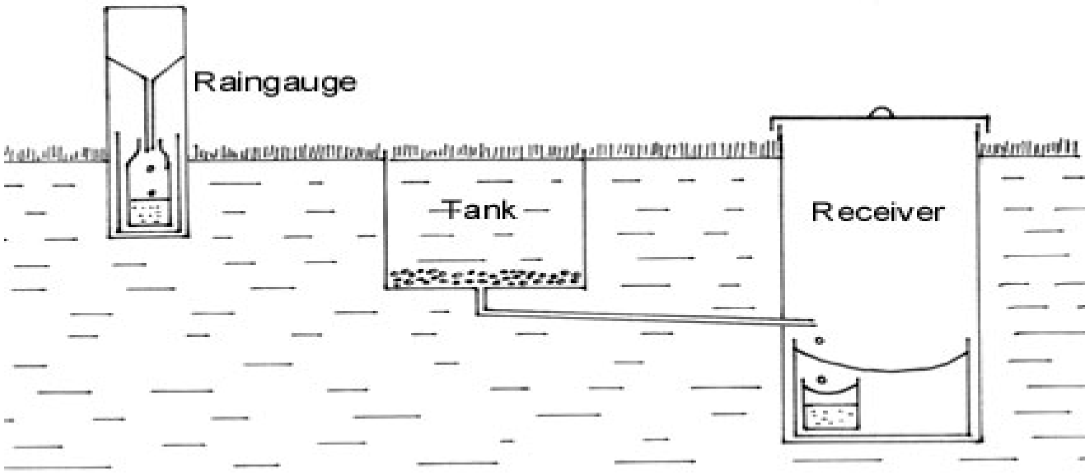

Fig. 1. Components of a Lysimeter.

Water Chemistry

Several parameters were analyzed for both the groundwater and the leachate that was prepared from the soil sample extracts that were collected from the study area. The primary emphasis was placed on parameters like nitrate, nitrite, ammonia, hydrogen sulphide, phosphate, sulphate, chloride, dissolved oxygen (DO), chemical oxygen demand (COD) and biological oxygen demand (BOD). Additionally, other elements and compounds were also determined, including calcium, sodium, magnesium, potassium, manganese, iron, aluminum, mercury, arsenic, boron, selenium, total hydrocarbon, dissolved organic carbon (DOC), halogenated organic compounds (AOX), polycyclic aromatic hydrocarbons (PAHs), and BTEX compounds.

Results of the chemical analyses of the groundwater samples and the leachate of the collected soil samples are presented in Tables 1 and 2.

Table 1. Chemical Analyses Results of Groundwater Samples Collected from the Study Area.

Sample ID	NO_3-N (mg/l)	NO_3 (mg/l)	NH_4^+ (mg/l)	NH_3 (mg/l)	TOC (mg/l)	BOD (mg/l)	COD (mg/l)	TPH (mg/l)
SF-01	71.0	312.4	0.8	0.755	9.0	3.0	54.0	0.822
SF-02	11.6	51.04	0.4	0.378	5.35	5.0	18.8	1.097
SF-03	22.8	100.32	0.4	0.378	2.49	0.0	20.0	-
SF-04	10.0	44.0	0.2	0.189	2.05	0.0	50.2	-
SF-05	27.2	119.7	0.4	0.378	3.31	1.0	19.1	-
SF-06	7.8	34.32	0.0	0.0	2.94	0.0	15.8	-
SF-07	15.9	70.0	0.0	0.0	1.80	0.0	16.0	-
SF-08	78	343.2	0.3	0.283	1.07	0.0	8.0	-

- Not analyzed.

Table 2. Chemical Analyses Results of Groundwater Samples Collected from the Study Area.

Sample ID	PO_4^{-3} (mg/l)	SO_4^{-2} (mg/l)	S^{-2} (mg/l)	Cl^- (mg/l)	Al^- (mg/l)	Hg (ppb)	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	Total Hardness as $CaCO_3$ (mg/l)
SF-01	7.7	3700	0.0	0.3	0.0	<10	862	116	2155
SF-02	3.5	1200	0.0	1.8	0.0	<10	240	14.65	600
SF-03	5.2	2900	0.0	0.7	0.0	<10	632	4.88	1580
SF-04	5.7	1700	0.0	5.1	0.0	<10	490	42.73	1225
SF-05	0.2	2900	0.0	2.6	0.0	<10	764	76.0	1910
SF-06	0.8	1900	0.0	3.1	0.0	<10	560	100	1400
SF-07	1.0	3300	0.0	0.0	0.0	<10	468	36.63	1170
SF-08	0.8	3000	0.0	0.0	0.0	<10	900	146.5	2250

Column Study. Soil samples were collected from selected locations (both irrigated and non-irrigated) within the study area at intervals of 10 cm down to a depth of 1 meter below the ground surface. These samples were used to construct soil columns in the laboratory and the irrigation water was allowed to infiltrate through the columns for various lengths of time. Water samples were regularly collected from the soil columns and were analyzed for the same chemical components of the collected groundwater. The results of the chemical analyses of the collected water samples from the soil columns are presented in Table 3, and these results along with the conducted soil column tests were used to understand the biogeochemical processes that are working at the site.

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Table 3. Results of Chemical Analyses of Inlet and Outlet Water Samples Collected from the Soil Columns.

Parameter (mg/l)	Inlet Water	Outlet Water (Non-Irrigated Site)	Outlet Water (Irrigated Site)
NO_3	10.56	44.0	17.6
NH_3	8.21	1.13	0.2
H_2S	0.0	0.0	0.0
PO_4^{-3}	37.4	3.8	13.5
SO_4^{-2}	200	2200	260
Cl^-	-	6.9	19.3
DO	-	-	-
COD	69.0	389	58.4
BOD	-	-	-
TOC	16.21	72.2	6.55
TPH	-	-	-
Total Hardness as $CaCO_3$	279.6	-	157.2
Ca^{+2}	111.8	-	62.9
Mg^{+2}	13.1	-	9.87
Al^-	-	-	-
Hg	<10 ppb	<10 ppb	<10 ppb

- Not analyzed.

Concluding Remarks

The obtained results indicate a decreasing trend with depth of the main parameters under investigation. Thus soil aquifer treatment (SAT) appears to be operating in the UAPCO farm area.

The results of the soil column studies indicate that at the irrigated sites, most of the sulfates and organic carbon have leached out from the unsaturated zone resulting in only slight enrichment (in case of sulfate) or some adsorption (in case of organic carbon) of these components as the treated wastewater passes through the soil. At the non-irrigated sites, however, the soil, in its pristine condition, is rich in sulfate and organic carbon, and the treated wastewater used for irrigation, leaches out these components as it infiltrates soil at these sites. The nitrification process appears to be working in both types of soil with the decrease in ammonia concentration and increase in the nitrate content in the outlet water samples compared to that in the inlet water (treated wastewater) sample.

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