WASTEWATER CHARACTERIZATION AND THE REUSE OF RECYCLED EFFLUENT IN IRRIGATING AGRICULTURAL CROPS

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ABSTRACT

Reusing of treated effluent that is normally discharged to the environment from municipal wastewater treatment plants is receiving an increasing attention as a reliable water resource. The volume of this resource is being considered in the planning and implementation of water resources projects.

Irrigating agricultural crops with recycled wastewater has been practiced in arid and semi arid regions and is rapidly getting popular in the countries of the Middle East. In Palestine and Jordan, irrigation with wastewater of different qualities has been practiced for along time.

Most traditional municipal wastewater treatment plants produce secondary treated recycled effluent with high amounts of Total Dissolved Solids, TDS, concentrations and other constituents that affect soil, crop and the environment. To avoid the negative affects proper irrigation management systems are required to avoid soil deterioration and reduction in yield.

In this paper, the author intends to introduce and discuss the procedures and methods used for characterization of wastewater, the

different parameters used to determine the quality of recycled water and the effects of recycled effluent on soil, crop and the environment.

KEYWORDS: Effluent, Irrigation, Reuse, Salinity, Wastewater

INTRODUCTION

The reuse of treated effluent that is normally discharged to the environment from municipal wastewater treatment plants is receiving an increasing attention as a reliable water resource. The volume of this resource is being considered in the planning and implementation of water resources projects.

In the United States, it was reported that in 1995 the reuse of recycled wastewater approached 3.85 million cubic meters of which 2.72 million cubic meters were reused in irrigating agricultural crops (Solley et al., 1998). This amount of reclaimed water reuse for 1995 in the United States represented an increase of 36% from 1990.

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In 2002, it was reported by the Palestinian Water Authority that the total expected treated effluent that would be available for irrigating agricultural crops would reach 92 million cubic meters in 2020. Figure 1 shows the predicted increasing trends in reusing treated effluent in irrigation in Palestine.

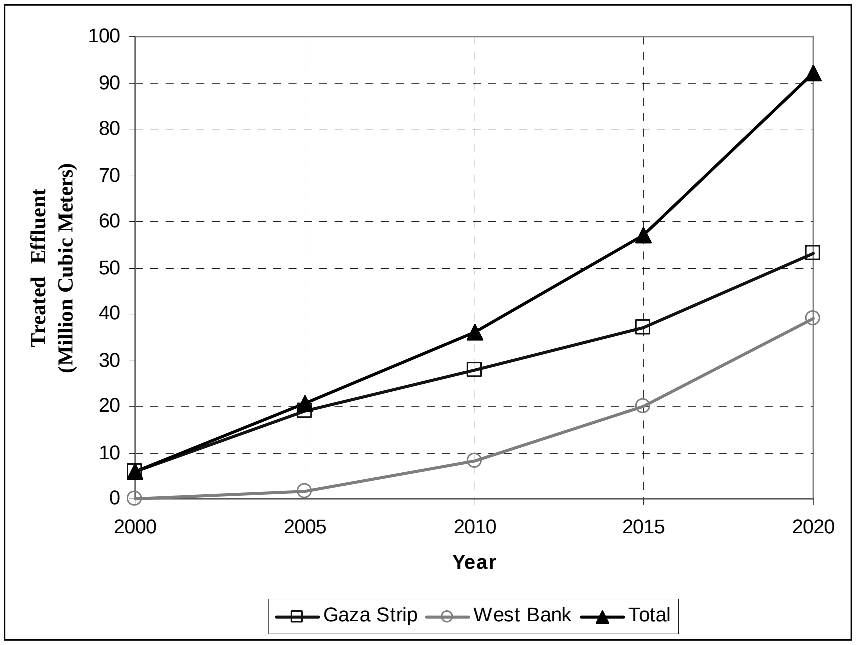

Figure 1: Predicted quantities of treated effluent that would be used in irrigation in Palestine

In Jordan and according to the Water Authority of Jordan about 60 million cubic meters of treated effluent were reused in irrigating agricultural crops in 1995 which increased to about 72 million cubic meters in 1998. Water Authority of Jordan is predicting that amount to increase to about 140 million cubic meters in 2010 due to the rapid construction of wastewater treatment plants.

Characterization of Wastewater

Wastewater characterization is very important when designing a wastewater treatment plant. Extensive data is collected and used to model biological processes such as the case in activated sludge systems. In addition, characterization of the effluent is import to determine the reuse safe options.

<u>Definition</u>

Every community produces liquid waste, solid waste and gas emissions. The liquid waste is usually termed wastewater. Therefore, wastewater can be a combination of the liquid or the water-carried wastes removed from residence, institutions, commercial and industrial establishments, ground water, surface water and storm water.

Wastewater Characteristics

Wastewater is generated from domestic and industrial sources. Industrial sources throughout the world are dumping 10,000 new organic compounds each year. These compounds need to be properly handled and removed if they cause health problems. Many industrial plants are required to pre-treat their wastewater before dumping it in the wastewater network.

Physical Characteristics

The most important physical characteristic of wastewater is its total solids content. The different physical characteristics are discussed below.

Solids

Wastewater contains a variety of solid materials varying from rags to colloidal material. In the characterization of wastewater, coarse solids are usually removed before the sample is analyzed for solids.

Total Solids

Total solids, TS, are defined as the residue remaining after a wastewater sample has been evaporated and dried at a temperature of 103 to 105^{o} C.

Total Suspended Solids

Total Suspended Solids, TSS, are defined as the portion of TS retained on a specific size filter after drying at 105 degrees C. Usually the Whatman glass fiber filter with a nominal pore size of 1.58 micron is used.

Total Dissolved Solids

Total Dissolved Solids, TDS, can be defined as the solids that pass through a filter with nominal pore size of 2 microns or less. The TDS can be calculated using the following equation:

$$TDS = (TS - TSS)$$

Volatile and Fixed Solids:

Volatile solids are defined as those solids that can be volatilized and burned off when ignited in a muffle oven a t $500 \pm 50^{o} C$. They are assumed to be organic matter.

Fixed solids are defined as the residue that remains after a sample has been ignited in a muffle oven.

TS, TSS and TDS are comprised of both fixed and volatile solids. The ratio of VS to FS (organic to non-organic matter) is used to characterize the wastewater in respect to amount of organic matter present in the wastewater.

Inorganic Nonmetallic Constituents

The source of inorganic nonmetallic constituents in wastewater comes from the water supply and from the addition of highly mineralized water from private wells, ground water and from industrial use.

Because concentrations of various inorganic constituents in wastewater can greatly affect the beneficial uses made of the treated effluent, the constituents must be considered separately.

pH

The concentration range suitable for the existence of most biological life is typically 6 to 9. Wastewater with an extreme concentration of hydrogen ion is difficult to treat by biological means. *pH* can be calculated using the following equation:

$$pH = -\log_{10}\left[H^{+}\right]$$

Chlorides

Chloride is a constituent of concern in wastewater because it affects the final reuse application of treated effluent.

Conventional methods of wastewater treatment do not remove Chloride and hence if chloride is high in wastewater, the contributing sources need to be investigated and reduced for a beneficial use to be considered.

Alkalinity

Alkalinity can be defined as the ability of wastewater to neutralize acids; it is a measure of buffering capacity against a *pH* drop.
Alkalinity results from the presence of the following ions in wastewater:

1. Hydroxides ion: OH^-

2. Carbonates ion: CO_3^{2-}

3. Bicarbonates ion: HCO_3^-

These ions can be present with elements such as calcium, magnesium, sodium, potassium and ammonia. Calcium and magnesium carbonates and bicarbonates are the most common. It should be mentioned here that wastewater is normally alkaline.

Nitrogen

Nutrients such as Nitrogen and phosphorus are essential elements for the growth of microorganisms, plants and animals. Nitrogen is the building block in the synthesis of protein and hence the quantity in wastewater is essential to be known to determine if the wastewater is treatable. Some times, if there is no enough nitrogen in the wastewater, quantities are added to make sure that biological processes can take place when treating wastewater.

Phosphorus

Phosphorus is also considered as a nutrient that is essential for the growth of plants, algae and other biological organisms. Municipal wastewaters may contain 4 to 16 mg/ltr of phosphorus. This value can be a lot higher in communities where detergents of high phosphorus contents are used such as the case in Palestine.

Sulfur

The sulfur ion is present in wastewater. It is required in the synthesis of proteins and is released in their degradation.

Biologically, sulfate is reduced under anaerobic conditions to sulfide, which then combines with hydrogen to form hydrogen sulfide (H_2S).

Hydrogen sulfide gas is usually entrapped in sewer pipes that are not running full which is usually the case. Then hydrogen sulfide gas can be oxidized biologically and produce sulfuric acid H_2SO_4 that is corrosive to concrete sewer pipes and it negatively affects the biological processes when sulfide concentration exceeds 200 mg/ltr.

When hydrogen sulfide gas is mixed with other wastewater gases such as Methane, CH_4, and CO_2, then the combination is corrosive to metal pipes and can explode producing a huge force.

Metallic Constituents

Trace quantities of many metals are important constituents of most waters. Many of these metals are also classified as priority pollutants, pollutants that are can cause cancers. But most of these metals are necessary for the growth of biological life. The presence of any of theses metals in excessive quantities will interfere with many beneficial uses of the water because of their toxicity.

Therefore, it is desirable to control the concentration of heavy metals when considering reuse options such as the case of controlling Boron concentration when the treated effluent is planned to be used for irrigation agricultural corps.

Organic Compounds

Organic compounds are usually composed of a combination of:

a) Carbon
b) Hydrogen
c) Oxygen
d) Nitrogen in some cases.

<u>Biochemical Oxygen Demand: BOD</u>

The most widely used parameter of organic pollution applied to both wastewater and surface water is the 5-day BOD (BOD_5). Results of the BOD tests are used to:

a. Determine the approximate quantity of oxygen that will be required to biologically stabilize the organic matter present in wastewater.

b. Determine the size of waste treatment facilities.

c. Measure the efficiency of some treatment process.

d. Determine compliance with wastewater discharge permits.

Total Chemical Oxygen Demand (COD)
The COD test is used to measure the oxygen equivalent of the organic material in wastewater that can be oxidized chemically using dichromate in an acid solution. The value of the COD is usually different than the value for BOD. Many organic substances which are difficult to oxidize biological can be oxidized chemically. COD test take about 2.5 hours compared to the 5-day BOD test.

Pathogenic Organisms

The source of pathogenic organisms found in wastewater can be excreted by human beings and animals who are infected or carriers of a particular infectious disease. There are four categories of pathogenic organisms found in wastewater. These are: Bacteria, protozoa, helminthes and viruses.

EFFECTS OF SECONDARY TREATED EFFLUENT ON CROP, SOIL AND THE ENVIRONMENT

Conventional wastewater treatment plants produce secondary treated effluent and don't remove total dissolved solids during the treatment processes causing the recycled wastewater to contain high concentrations of salts. When used for irrigation, its quality threatens the environment, human health and sustainability of crop production.

This effluent contains some pathogens and its chlorination or bromination may generate harmful compounds. Prolonged use of secondary effluent in irrigation induces soil salinity and alkalinity, which are harmful to soil and to plant growth.

Secondary effluent is presently used for irrigation world wide and in the countries of the Middle East. Even if the biological and chemical oxygen demands (BOD and COD) are reduced by the process, indicating reduced levels of organic matter and biological activity, the use of this effluent may pose environmental and health hazards. It may contain pathogens, and toxic elements and compounds. In the long run, irrigation with such an effluent will raise the soil salinity and alkalinity to detrimental levels. Therefore to ensure the sustainability of reusing treated effluent in irrigating crops, irrigation management systems and procedures need to be developed and used for the arid and semi arid regions where most of the treated effluent nowadays is used, to prevent catastrophic deterioration of soils and ground water.

Pathogens can directly affect the health of agricultural workers and indirectly that of the public consuming the irrigated crops (Regli et al., 1991), (Feachem et al., 1983) and (Cooper, 1991). Reuse criteria were established by governments and international bodies such as The World Health Organization (1989); CIHEAM (1988) and US EPA (1992).

Salinity, boron, and nitrogen have direct physiological effects on plants, whereas high sodium expressed by the adjusted Sodium Adsorption Ratio, adj R_{Na}, affects soil properties that can indirectly affect plant growth.

Suspended organic and inorganic solids and microbial products may cause operational problems in irrigation systems, especially emitter clogging in drip irrigation. Organic matter added to soil with the effluent, may enhance the mobility of heavy metals and pesticides, increase the harmful exchangeable sodium and cause deterioration of soil hydraulic properties

PROPER MANAGEMENT OF IRRIGATION SYSTEMS USING RECYCLED WATER

Numerous irrigation water quality guidelines have been proposed in the literature to reduce the affects of using recycled water in irrigating agricultural crops. The guidelines presented in table 1 below were developed by the University of California Committee of Consultants and expanded by others to determine the long term influence of water quality on crop production and soil conditions.

To avoid the negative affect, a proper irrigation management system is required to avoid soil deterioration and reduction in yield.

Advanced irrigation systems with proper management, such as drip irrigation systems, offer high water application efficiency and uniformity, facilitate irrigation and fertilization management and thus afford improved leaching control. These irrigation methods also minimize the contact of the crop with the applied effluent.

CONCLUSIONS

Reuse of treated wastewater in agriculture can have devastating results on the soil, environment, and public health, especially in arid and semi arid regions, if implemented hastily. Appropriate data collection, analysis, designs, testing, evaluation then implementing the best suitable system is the proper course of action that needs to be taken when considering such a problem.

Palestine and Jordan suffer from scarce water resources. Treated wastewater is a valuable resource that can be used to augment fresh water use in agriculture. The increasing demand on water resources sometimes make people compromise the natural resources, the environment and public health. If this is allowed then the price will be very high for the coming generations.

Table 1: Guidelines for Interpretation of Effluent Quality for Irrigation[ξ]

Potential Irrigation Problem	Parameter	Range	Units	Degree of Restriction on Use		
				None	**Slight to Moderate**	**Severe**
Salinity	ECw		dS/m	ECw < 0.7	0.7 < ECw < 3.0	ECw > 3.0
	TDS		mg/ltr	ECw < 450	450 < ECw < 2000	ECw > 2000
Permeability	adj R_{Na} =	0-3	and	ECw ≤ 0.7	0.7 > ECw > 0.2	ECw < 0.2
	adj R_{Na} =	3-6	and	ECw ≤ 1.2	1.2 > ECw > 0.3	ECw < 0.3
	adj R_{Na} =	6-12	and	ECw ≤ 1.9	1.9 > ECw > 0.5	ECw < 0.5
	adj R_{Na} =	12-20	and	ECw ≤ 2.9	2.9 > ECw > 1.3	ECw < 1.3
	adj R_{Na} =	20-40	and	ECw ≤ 5.0	5.0 > ECw > 2.9	ECw < 2.9
Specific Ion Toxicity	***Sodium (Na)***					
	Surface Irrigation		adj R_{Na}	adj R_{Na} < 3	3 < adj R_{Na} < 9	adj R_{Na} > 70
	Sprinkler Irrigation		mg/ltr	[Na] < 70	[Na] > 70	
Specific Ion Toxicity	***Chloride***					
	Surface Irrigation		mg/ltr	$[Cl^-]$ < 140	140 < Cl^- < 350	$[Cl^-]$ > 350
	Sprinkler Irrigation		mg/ltr	$[Cl^-]$ < 100	Cl^- > 100	
Specific Ion Toxicity	***Boron (B)***		mg/ltr	[B] < 0.7	0.7 < B < 3.0	[B] > 3.0

Specific Ion Toxicity	***Nitrogen (Total-N)***		mg/ltr	[Total-N] < 5	5 < Total-N < 30	[Total-N] > 30
Specific Ion Toxicity	***Bicarbonate (HCO_3)***		mg/ltr	[HCO_3] < 90	90 < HCO_3 < 500	[HCO_3] < 500
	pH		unit	Normal	Range: 6.5 - 8.4	

$^{\xi}$Adapted from Metcalf & Eddy (2003)

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