SUSTAINABLE DEVELOPMENT AND REUSE OF WASTEWATER

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INTRODUCTION

Water resources in Egypt are becoming scarce. Surface water resources originated from the Nile are now fully exploited, while groundwater sources are being brought into full production. Egypt is facing increasing water needs, demanded by a rapidly growing growth population, by increasing urbanization, by higher standards of living and by an agricultural policy which emphasis expanded production in order to feed the growing population. (Hvidt, 2000)

Reuse of wastewater in agriculture may serve both as a waste disposal method and as a supplementary unconventional water source for irrigation in areas that suffer from water scarcity. Potential risks and environmental impacts resulting from wastewater reuse in irrigation and alternative management measures for reuse with acceptable risks are of great importance to be identified. (Mowelhi, 1997)

The physical and chemical properties and microbiological constituents of wastewater are important parameters in the design and operation of collection, treatment and use of treated effluent. Reuse of reclaimed wastewater may adversely affect public health and the environment of particular concern is degree of purification but also the selection of the most appropriate methods of irrigation and the water use efficiency by which wastewater is applied at the farmers level irrigation method and scheduling of irrigation are important components in the overall system for efficient and safe use of the reclaimed wastewater on environmentally sound bases. (Asano et al, 1984)

Irrigation with wastewater has been extensively practiced with traditional irrigation methods over the centuries. Some of these methods are still used, but recently modern irrigation technology has been developed and widely accepted. This new technology, although very useful with all irrigation waters, might be of particular interest in practicing irrigation with effluents. (Doneen and Westcot, 1984)

The selection of the appropriate method depends on the quality of the effluent, the crop to be grown, the tradition, background and skill of the farmers on the different methods, and the potential risk to the health of workers, public and environment. In relation to disease transmission control, some advantages and disadvantages characterize the various methods. (Mara and Cairncross, 1987)

RESEARCH SCOPE

The aim of this paper is to

- Implement guidelines for treated wastewater reuse in irrigation.
- Suggest appropriate methods for irrigation with treated wastewater.

MATERIALS AND METHODS

Case study (1): El-Saff drain (Agriculture wastewater)

That is located in Helwan at 871.3 Km from High Aswan Dam at the River Nile's Right Bank; it is used as a drain for agriculture excess water. Agricultural lands that get rid of its excess water in the drain through a pipe that collect this water and discharge it in the drain.

Case study (2): El-Sadat (Urban wastewater)

El-Sadat municipality is located 90 Km north of Cairo. It's home to approximately 20,000 residents. The town includes recreational areas, an industrial zone for carpet and tile production, and citrus and olive agricultural areas. An oxidation pond is used to treat the wastewater of El-Sadat City.

Samples were collected from the specified locations monthly through years 1999 and 2000 using autosamplers in polyethylene containers that were washed first with tap water, distilled water then by the sample before putting the sample in it. These samples were preserved according to "Standard method for examination of water and wastewater" and then transported to the laboratory in ice tanks within few hours.

Water samples were analyzed in situ for temperature, pH and electrical conductivity (EC). In laboratory physicochemical parameters as (pH, EC, alkalinity and solids) and chemical parameters as (Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), trace metals, major anions and cations). While SAR (Sodium Adsorption Ratio) was calculated using equation (1) (FAO, 1976).

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \qquad \text{………..} (1)$$

Na = Sodium in (meq/l)

Ca + Mg = Calcium + Magnesium in (meq/l)

Averages were calculated for all the parameters for year 1999 as well as for year 2000 samples. Planning of alternative crop patterns has been evaluated based on qualitative analysis of water.

1. Physicochemical Analyses

Chemical and bacteriological reactions increase with increasing temperature. Temperature was measured using mercury filled Celsius thermometer.

The measurement of pH produces an indication of the balance between the acids and bases in water. The measurement of the hydrogen ion concentration in solution reflects the solvent power of water, thereby indicating its possible chemical reactions on rocks and soils. The presence of carbonates, hydroxides and bicarbonates increases the basicity of water (pH>7), while the presence of free mineral acids and carbonic acids increases its acidity (pH<7). Acid waters are less common than alkaline waters. It is measured using pH/ISE meters, ORION model 710A.

The Electrical conductivity of a solution (EC) is the ability of the solution to carry an electric current. Since the current is carried in the solution by the migration of the solute ions, the conductivity has some relationship to the total ionic concentration of the solution. The standard unit of the electrical conductivity is the reciprocal of the resistance in Ohms and is written in terms of decisiemens per centimeter (dS/cm), at 25^0C.

Sodium Adsorption Ratio (SAR) is calculated as shown in Equation (1).

The solids of an aquifer sample provide a measure of the total solids (TS), total dissolved solids (TDS) and total suspended solids (TSS). The presence of such solutes alters the physical and chemical properties of water. Gravimeteric method is being used to determine TS, TDS while TSS is calculated from TS and TDS values.

2. Oxygen Demand Analysis

Biochemical Oxygen Demand (BOD) is the measure of the amount of oxygen required by bacteria to oxidize waste aerobically to carbon dioxide and water while Chemical Oxygen Demand (COD) is the measure of the oxygen susceptible to oxidation by a strong chemical oxidant. The COD values are greater than BOD values, but its handicap is the inability to show a difference between biologically oxidizable and biologically inert organic matter.

It is measured using ORION BOD fast respirometery system model 890 with measuring range 0-4000 mg/l at 200C incubation in a thermostatic incubator chamber model WTW.

3. Major Anions and Cations

Major anions concentration were determined using Ion Chromatography (IC), model DX-500 chromatography system while cations is measured using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) with ultrasonic nebulizer (USN), this nebulizer decrease the instrumental detection limits by 10%, this ICP instrument is Perkin Elmer Optima 3000, USA.

4. Trace Metals

At high concentration trace metals such as aluminum, arsenic, barium, beryllium, cadmium, cobalt, copper, nickel, lead, iron, manganese, chromium, mercury, vanadium, strontium and molybdenum can be dangerous to humans and lower living organisms. Some of these metals such as aluminum, barium, beryllium, etc are toxic at low concentration.

Trace metals are measured using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) with ultrasonic nebulizer (USN), this nebulizer decrease the instrumental detection limits by 10%, this ICP instrument is Perkin Elmer Optima 3000, USA.

RESULTS AND DISCUSSION

1. Physicochemical Analyses

Table (1) shows that samples temperature ranges between 23^0C to 33^0C; lower temperature were recorded for year 1999.

Sadat and El-Saff water can be used for irrigation without problem where pH values average (basicity) is 7.85 for El-Saff samples and 8.5 for Sadat samples.

The Electrical Conductivity of El-Saff samples ranged between 0.57 (1999) and 0.60 dS/cm (2000) while in the El-Sadat samples values ranged between 1.6 (1999) and 1.7 dS/cm (2000). For El-Saff water it can be considered non-saline but for Sadat water it is slightly saline water.

Concerning the SAR (Sodium Absorption Ratio), values obtained for El-Saff samples ranged between 1.18 and 0.79 and El-Sadat samples ranged from 8.75 to 8.7. It is clear that for using Sadat and El-Saff waters in irrigation, there will be no effect of sodium ions in reducing the infiltration rate and soil permeability.

Table (1): Results of physicochemical parameters

Parameter	Unit	Sadat (1999)	Sadat (2000)	Saff (1999)	Saff (2000)	FAO standards
Temp.	°C	31.0	33.0	23.0	30.2	-
PH	----	8.4	8.6	7.8	7.9	6.5-8.4
EC	dS/cm	1.60	1.70	0.57	0.60	1-5
SAR	----	8.75	8.70	1.18	0.79	--
TS	mg/l	1124	1050	269	334	--
TDS	mg/l	705	874	256	312	450
TSS	mg/l	439	176	13	22	30

2. Oxygen demand Analysis

Table (2) shows a BOD of 1.7 to 1.0 mg/l for El-Saff samples and El-Sadat samples from 71.5 to 60.0 and COD of from 2.8 to 1.7 for El-Saff samples and for El-Sadat samples ranged from 94.5 to 75.0.

Table 2: Results of BOD and COD

Parameter	Unit	Sadat (1999)	Sadat (2000)	Saff (1999)	Saff (2000)
BOD	mg O2/l	71.5	60.0	1.7	1.0
COD	mg O2/l	94.5	75.0	2.8	1.7

3. Major Anions and Cations

Determination of the common cations such as calcium, magnesium, boron, sodium, potassium and anions such as bromide, chloride, fluoride, nitrate, nitrite, phosphate and sulphate often is desirable to characterize water and/or to assess the need for specific treatment.

Analysis results (Table 3) shows higher sodium, a potassium, sulphate and chloride concentration at El-Sadat than El-Saff samples.

Table 3: Results of major anions and cations

Parameter	Unit	Sadat (1999)	Sadat (2000)	Saff (1999)	Saff (2000)
Calcium (Ca)	mg/l	23.65	24.05	44.3	25.45
Magnesium (Mg)	mg/l	14.59	15.44	14.71	9.6
Sodium (Na)	mg/l	81.63	72.2	37.48	18.6
Potassium (K)	mg/l	83.69	83.3	5.47	5.08
Sulfate (SO_4)	mg/l	292.98	302.11	28.82	14.89
Chloride (Cl)	mg/l	166.6	170.15	21.6	9.22
Bicarbonate (HCO_3)	mg/l	118.97	106.77	131.79	139.72

4. Trace metals

Analysis results are shown in Table (4) showing chromium and cadmium is not detected (ND).

Table 4: Trace metals concentration in Sadat and Saff water samples collected through years 1999 and 2000

Parameter	Unit	Sadat (1999)	Sadat (2000)	Saff (1999)	Saff (2000)	FAO Standards
Copper (Cu)	mg/l	0.30	0.24	0.44	0.061	0.2
Iron (Fe)	mg/l	0.27	0.26	0.41	0.21	5.0
Nickel (Ni)	mg/l	0.13	0.02	ND	0.15	0.2
Zinc (Zn)	mg/l	0.24	0.15	0.047	0.21	2.0
Lead (Pb)	mg/l	0.01	0.018	ND	ND	5.0
Manganese	mg/l	0.96	1.20	0.097	0.032	0.2
Cobalt (Co)	mg/l	0.01	0.02	ND	ND	0.05

By comparing the results of the parameters in table (4) with the FAO standard limits it is found that for El-Sadat; Cu and Mn exceeds the FAO standard limits, while for El-Saff Drain all the parameters are under these limits.

From all the above, we can conclude that El-Sadat wastewater exceeds the FAO standard limits for TDS, TSS, Cu and Mn, however it can be used for irrigation but after taking some precautions and selecting the suitable irrigation system.

SELECTING OF IRRIGATION METHODS

Under normal conditions, the type of irrigation method selected will depend on water supply condition, climate, soil, crops to be grown, cost of irrigation method and the ability of the farmer to manage the system. However, during wastewater reuse, other factors such as plant contamination, harvested product, farm workers, also environmental, salinity and toxicity hazards will need to be considered (FOA/RNEA, 1993). There is good scope to reduce the undesirable effects of wastewater reuse in irrigation through selection of appropriate irrigation methods.

Traditional Irrigation Systems

Water is applied directly to the soil surface either by controlled flooding or in some kind of furrow. In controlled flooding the water applied to the surface is controlled by dikes and ditches.

Surface, or gravity, (waste water) application can be accepted only provided that irrigators are sufficiently protected by the contact, including inhalation, and that crops to be irrigated are industrial, forage or tree crops.

Modern Irrigation Systems

Wastewater and irrigation: technological problems

Before going ahead to irrigate with wastewater through modern irrigation system some awareness must be taken against clogging of emitter or sprinkler orifices. (Bucks et al, 1979; Bos-well, 1993 and Capra et al. (1997, 1998).

Filtration

For a general-purpose filtration, screen or disc filters are universally used, with passage orifices more or less narrow according to the need the filtration depth is conventionally expressed in "mesh", namely the number of orifices existing in an inch of the screen, ranging between 20 to 120 or more. (Table5)

The general rule is that the diameter in the filter passage should never exceed 1/5 to 1/7 of the emitter orifice; this in order to avoid the so-called "bottleneck effect" of the impurities. The table below gives correspondence between number of mesh, filter hole diameter and emitter orifice diameter.

Table (5): Correspondence among Filter Meshes, Filter Holes and Emitter Orifices

Mesh	20	40	80	100	120	150	180	200
Filter hole diameter, mm	0.711	0.420	0.180	0.152	0.125	0.105	0.089	0.074
Emitter orifice diameter, mm	5	3	1.2	1.0	0.9	0.7	0.6	0.5

In theory some filters have the possibility of self- cleaning, however in practice this sophisticated solution is costly and seldom, if ever, operates as desired.

In conclusion, when possible, the simplest and cheapest solution can be found in a combination of open gravity pre-filters and simple manually operated screens or discs filters.

Sprinkler or Spray Irrigation Methods

Those irrigation methods are generally more efficient in terms of water use (FAO/RNEA, 1992). However, these overhead irrigation methods may contaminate ground crops, fruit trees and farm workers.

Sprinkler systems are more affected by water quality than surface irrigation systems, primarily as a result of clogging orifices in sprinkler heads, potential leaf bums and phytotoxicity when water is saline and contains excessive toxic elements. Secondary wastewater treatment has generally been found to produce an effluent suitable for distribution through sprinklers provided that the effluent is not too saline.

Drip Irrigation Systems

This method, in general, might be the one to be recommended for irrigation with effluent. Moreover, no aerosols are formed and therefore, no pollution of the atmosphere and of the area nearby to the irrigated fields occurs (Papadopolous, 1991 and FAO/RNEA 1992a, l993). However, the high concentration of suspended solids may interfere with the flow of water in pipes and emitters. Clogging of emitters becomes a major concern. Therefore, water quality is of primary importance in the design operations of a maintenance program.

Generally, municipal waters that have been filtered and chlorinated for controlling disease-causing bacteria are the least troublesome. But treatment of agricultural water to this quality can be impractical uneconomical, Table (6)

Table (6): Contributors to clogging of localized (drip) irrigation systems as related to irrigation water quality (adapted from Bucks et al., 1979)

Physical (Suspended Solids)	Chemical (Precipitation)	Biological (Bacteria and algae)
Sand	Calcium or magnesium carbonate	Filaments
Silt	Calcium sulphate	Slim
Clay	**Heavy metal** hydroxides, oxides, carbonates, silicates and sulphide	**Microbial depositions**: • Iron • Sulphur • Manganese
Organic matter	**Fertilizers** • Phosphate • Aqueous ammonia • Iron, zinc, copper, manganese	1. Bacteria 2. Small aquatic organisms • Snail eggs • Larva

For all mentioned irrigation systems, suspended solids should be removed as much as possible before sewage is used. In this regard, the screen filtration could have an essential role in diminishing the problems created by solids in the effluents or biological growth at the emitters.

Table (7): Influence of water quality on the potential for clogging problems in localized (drip) irrigation systems (adapted from Nakayama, 1982)

Potential problem	Units	Degree of Restriction on use		
		None	**Slight to moderate**	**Serve**
Physical				
Suspended solids	mg/l	<50	50 - 100	> 100
Chemical				
PH		< 7.0	7.0 – 8.0	> 8.0
Dissolved solids	mg/l	< 500	500 - 2000	> 2000
Manganese1	mg/l	< 0.1	0.1 – 1.5	> 1.5
Iron2	mg/l	< 0.1	0.1 – 1.5	> 1.5
Hydrogen Sulphide	mg/l	< 0.5	0.5 – 2.0	> 2.0
Biological			Maximum	
Bacterial populations	no/ml	< 10000	10000 - 50000	> 50000

1. While restrictions in use of localized (drip) irrigation systems may not occur at these manganese concentrations, plant toxicities may occur at lower concentrations
2. Iron concentrations > 5.0 mg/l may cause nutritional imbalances in certain crop

Bubbler Irrigation

It is a localized irrigation technique with regulated flow developed for irrigating fruit trees with effluent. It performs better than trickles and mini-sprinklers as far as clogging is concerned and, therefore, requires less maintenance.

Sub-Surface Irrigation

It can be achieved either by controlling the depth of an existing water table (conventional), or by a sub-surface irrigation system (localized). In both cases, water is supplied to the root zone with minimum, if any, contact risk to agricultural workers as well as to crop foliage or aerial organs.

Efficiency of surface irrigation methods in general, borders, basins, and furrow, are greatly affected by water quality, although the health risk inherent in these systems most certainly is. Some problems might arise if the effluent contains large quantities of suspended solids and these settle out and restrict flow in transporting channels, gates, pipes, and appurtenances. The use of primary treated sewage will prevent such problems. To avoid health risk from using surface irrigation, effluent, land leveling should be carried out carefully and appropriate land gradient.

Sprinkler, or spray, irrigation methods are generally more efficient in terms of water use. Greater uniformity of application can be achieved. However, these overhead irrigation methods may contaminate ground crops, fruit trees and farm workers. In addition, pathogens contained in aerosolized effluent may be transported downwind and create health risk to nearby residents.

Generally, mechanized and automated systems have relatively high capital costs and low labor costs compared with manually moved sprinkler systems. Rough land leveling is necessary for sprinkler systems to prevent excessive head losses and achieved uniformity of wetting. Sprinkler system, are more effected by water quality than surface irrigation systems, primarily as a result of clogging orifices in the sprinkler.

Irrigation methods must also be examined in relation to the extent they are practiced in an area or country; the background of the people dealing effectively with certain methods, the crops to be irrigated an the extent of contamination they may induce on the crops, particularly the edible parts, in connection with the quality of irrigation effluent. (Table 8)

Table (8): Evaluation of common irrigation methods in relation to the use of treated sewage water (adapted from Mara and Cairncross, 1989)

Parameters of evaluation	Furrow Irrigation	Border irrigation	Sprinkler Irrigation	Drip Irrigation
Foliar wetting and consequent leaf damage resulting in poor yield.	No foliar injury and the crop is planted on the ridge.	Some bottom leaves may be affected. But the damage is not so serious as to reduce yield.	Severe leaf damage can occur resulting in significant yield loss.	No foliar occurs under this method of irrigation.
Salt accumulation in the root zone with repeated applications.	Salt tends to accumulate in the ridge, which could harm the crop.	Salt moves vertically downwards and is not likely to accumulate in the root zone.	Salt movement is downwards and root zone is not likely to accumulate salts.	Salts movement is radial along the direction of water movement. A salt wedge is formed between drip points.
Ability to maintain high soil water potential.	Plants may be subject to stress between irrigation.	Plants may be subject to water stress between irrigation.	Not possible to maintain high soil water potential throughout the growing season.	Possible to maintain high soils water potential throughout the growing season and minimizes the effect salinity.
Suitability to handle brackish water without significant yield loss.	Fair to medium. With good management and drainage acceptable yields are possible.	Fair to medium. Good irrigation and drainage practices can produce acceptable levels of yield.	Poor to fair. Most crops suffer from leaf damage and yield low.	Excellent to good. Almost all crops can be grown with very little reduction in yield.

CONCLUSION

It can be concluded that drip or bubbler irrigation system are the most suitable method will be used for urban wastewater (Sadat City) but after using automatic flushing filter because it has high TDS to avoid clogging in the emitter.

For agricultural wastewater (El-Saff City) all irrigation method can be used either by surface or modern irrigation but modern irrigation system will be more safety for the farmer.

RECOMMENDATION

Wastewater reuse for irrigation is an attractive solution not only for the possible savings in freshwater but also for the saving in fertilizers. However, some consideration must be taken:

- For selecting the most suitable irrigation method, the following must be considered:
    1. Crops are not for human consumption (cotton, sisal).
    2. Crops normally processed by heat or drying before human consumption (grains, oilseed, sugar beet).
    3. Vegetables and fruits grown for canning or other processing that effectively destroy pathogen.
    4. Fodder crops sun-dried and harvest before consumption by animals.
    5. Crops for human consumption that does not come into direct contact with wastewater (trees crops, vineyards, etc.).
    6. Crops for human consumption normally eaten after cooking (potatoes, eggplant, peet-roots), and also crops that the peel of which is not eaten (melons, watermelons, citrus, nuts).

- For modern irrigation system which used wastewater:

  All outlet, taps and valves must be secured and no cross connections with any pipeline or works conveying potable water.

- The provision for training is required not only before the use of wastewater through irrigation system, but from time to time thereafter, since, refreshing and up grading of skills and training of new personnel should be continuous process.

Finally, it’s the author’s opinion that in order to promote reuse of wastewater and to adapt it to all uses (irrigation, tourism, industry…) more study and research for the effects of using wastewaters on land, cultivations, environment and irrigation systems are needed.

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