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TREATMENT OPTIONS FOR WASTEWATER REUSE

BY

Prof. Dr. Javed A. Aziz

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ABSTRACT

Wastewaters may be reused for various purposes. Many agencies have established quality criteria for different reuse of treated effluents. This paper presents these criteria and emphasizes the need for the removal of pathogenic bacteria and helminth eggs for the reuse of wastewater in agriculture and of trematode eggs for aquaculture purposes. It is concluded that waste stabilization ponds can produce effluents suitable for unrestricted irrigation and aquaculture.

INTRODUCTION

In many parts of the world where water is scarce, wastewaters have been put to use for a variety of purposes. Such uses of wastewaters generally include crop irrigation, industrial (recirculation water), groundwater recharge, aquaculture, landscape irrigation and recreation. In particular there has been a notable increase in the use of wastewater for crop irrigation especially in the arid and seasonally arid areas of both industrialized and developing countries. Reasons to this effect include scarcity of alternative waters for irrigation, growing recognition of importance and value of wastewater reuse and high costs of artificial fertilizers.

For the present discussion on wastewater reuse, the term 'wastewater' refers to domestic sewage and municipal wastewaters that do not contain substantial quantities of industrial effluents. A distinction should also be made between direct and indirect reuse. Indirect reuse is where treated effluent loses its identity by dilution in a river or in groundwater and is subjected to some degree of 'self-purification' prior to abstraction. The indirect reuse has found extensive application in many countries including the U.K. where rivers carrying high proportions of effluents are used for water supply abstraction (Lumbers, 1986).

Reusing wastewater usually incurs some risks to human health and the potential environmental damage. These risks must be reduced to a level acceptable to the community. In order to mitigate the potential adverse impacts, restrictions in the form of criteria/standards or guidelines are imposed on the quality of the effluents with respect to their specific reuse. Based on the recommended/enforced restrictions, appropriate treatment methods may then be employed to produce the effluent of the desired quality.

Various reuses of wastewaters along with the effluent quality criteria and treatment options are discussed as follows.

[1] Director, Institute of Environmental Engineering and Research, University of Engineering and Technology, Lahore.

AGRICULTURAL REUSE

The value of wastewater for crop production has been recognized in many countries including the USA, Australia, Pakistan, India, China and the Middle-East. However, its use must be approached with caution. The reuse can only be feasible if both health risks and costs are minimized. Health considerations are centered around survival rates of pathogenic organisms, particularly in relation to the irrigation of health sensitive crops (including fruits and vegetables eaten raw). Associated environmental hazards are contamination of groundwater and accumulation of heavy metals and toxic organisms in surface soils and water. In agriculture, the major concerns are salinity, reduction in soil permeability and specific ion toxicity (Pescod and Arar, 1988).

Criteria

Microbial quality guidelines for wastewater reuse have been established in Engelberg Report (IRCWD, 1985). The report recognized that in many developing countries, the main risks were associated with helminth diseases and the safe use of wastewater would require a high degree of helminth removal. To protect the health of the field workers, the Engelberg guidelines, therefore, classify effluents for restricted and unrestricted use based on nematode eggs count and faecal coliform population. These guidelines are reproduced in Table 1.

Comprehensive chemical quality guidelines for wastewater reuse in agriculture have been recommended by FAO (1985) in which salinity, infiltration, toxicity and trace elements limits are covered. These guidelines are reproduced in Table 2. It may be mentioned that in municipal wastewaters, the inclusion of industrial wastes may add toxic compounds but not in detrimental quantities and only the boron sensitivity of the crop being irrigated needs considerations.

Table 1: Engelberg microbiological quality guidelines for treated wastewater reuse in agricultural irrigation (IRCWD, 1985)

Reuse Process	Intenstinal nematodes[a] (arithmetic mean no. of viable eggs per litre)	Faecal Coliforms (geometric mean no. per 100ml)
Restricted irrigation[b] Irrigation of trees, industrial not applicable crops, fodder crops, fruit trees[c] and pasture[d].	≤ 1	Not applicable
Unrestricted Irrigation Irrigation of edible crops, 1000 f sports fields, and public parks[e].	≤ 1	≤ 1000

a Ascaris. Trichuris and hookworms.
b A minimum degree of treatment equivalent to at least a 1-day anaerobic pond followed by a 5-day facultative pond or its equivalent is required in all cases.
c Irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground.
d Irrigation should cease two weeks before animals are allowed to graze.
e Local epidemiological factors may require a more stringent standard for public lawns, especially hotel lawns in tourist area.
f When edible crops are always consumed well cooked, this recommendation may be less stringent.

Treatment Options

The most appropriate wastewater treatment to be used for irrigation purposes should not only meet the above quality guidelines for unrestricted use but also at low cost and with minimum operational and maintenance requirements. Table 3 summarizes the available information on the removal of excreted bacteria and helminths in various treatment processes and indicates where Engelberg guidelines can be met (Mara and Cairncross, 1988).

Conventional sewage treatment plants which incorporate primary and secondary treatment stages alone are notoriously inefficient systems for the removal of excreted pathogens and helminths to meet the Engelberg guidelines. On the other hand selection of high technology tertiary treatment processes, including chlorination can virtually eliminate pathogenic bacteria. Nevertheless, chlorination of wastewater effluents is a vastly complex and unpredictable operation in terms of disinfecting efficiency. For this reason it should not be considered a viable treatment option particularly in the developing countries. In addition, chlorination will leave most helminth eggs totally unharmed and it is most unlikely that it will be effective in removing protozoal cysts (Faechem et al., 1983). Above all, the process is highly expensive. Tertiary treatment by rapid gravity sand filters, however, would achieve a low solid content and ensure adequate removal of helminth eggs. Its application along with conventional treatment processes may be evaluated for efficiency to meet the Engelberg guidelines.

In case of conventional treatment plants, a far more appropriate tertiary option is to add one or more polishing ponds in a series. Through their addition the resulting effluent can become suitable for reuse in agriculture. In places where land is limited, aerated lagoons can be evaluated for their potential use. Nevertheless, other treatment technologies which could be used as a second stage of treatment after aerated lagoons, such as filtration, microstraining, chemical coagulation and ovicidal disinfection should be considered to meet the Engelberg guidelines (Arar, 1988).

Table 2: Guidelines for interpretation of water quality for irrigation (FAO, 1985)

Potential Irrigation Problem	Units	Degree of Restriction on use		
		None	Slight to moderate	Severe
Salinity (affects crop water availability)[a]				
EC_w	dS/m	<0.7	0.7-3.0	>3.0
or				
TDS	mg/l	<450	450-2000	>2000
Infiltration (affects infiltration rate of water into the soil. Evaluation using EC_w and SAR together)[b]				
SAR = 0 - 3 and EC_w =		>0.7	0.7-0.2	<0.2
= 3 - 6 =		>1.2	1.2-0.3	<0.3
= 6 - 12 =		>1.9	1.9-0.5	<0.5
= 12 - 20 =		>2.9	2.9-1.3	<1.3
= 20 - 40 =		>5.0	5.0-2.9	<2.9
Specific ion toxicity (affects sensitive crops)				
Sodium (Na)[c]				
surface irrigation	SAR	<3	3-9	>9
sprinkler irrigation	me/l	<3	<3	
Chloride (Cl)[d]				
Surface irrigation	me/l	<4	4-10	>10
Sprinkler irrigation	me/l	<3	>3	
Boron (B)	mg/l	<0.7	0.7-3.0	>3.0
Trace elements				
Miscellaneous effects (affects susceptible crops)				
Nitrogen (NO_3 - N)[d]	mg/l	>5	5-30	>30
Bicarbonate (HCO_3) (overhead sprinkling only)	me/l	<1.5	1.5-8.5	>8.5
pH		Normal range 6.5 - 8.4		

a EC_w means electrical conductivity, a measure of the water salinity, reported in deci Siemens per meter at 25°C (dSm) or in units millimhos per centimeter (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per litre (mg/l).
b SAR means sodium adsorption ratio and is sometimes reported by the symbol RNa. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by EC_w.
c For surface irrigation, most tree crops and woody plant are sensitive to sodium and chloride: use the values shown. Most annual crops are not sensitive. With overhead sprinkler irrigation and low humidity (<30%), sodium and chloride may be absorbed through the leaves of sensitive crops.
d NO_3 - N, nitrate nitrogen, reported in terms of elemental nitrogen (NH^4 - N and organic - N should be included when wastewater is being tested).

Table 3: Expected removal of excreted bacteria and helminths in various wastewater treatment processes (Feachem et al, 1983).

Treatment Process	Removal (log_{10} units) Bacteria	Helminths	Viruses	Cysts
Primary sedimentation				
Plain	0-1	0-2	0-1	0-1
Chemistry assisted[a]	1-2	1-3 (E)	0-1	0-1
Activated Sludge[b]	0-2	0-2	0-1	0-1
Biofiltration[b]	0-2	0-2	0-1	0-1
Aerated lagoon[c]	1-2	1-3 (E)	1-2	0-1
Oxidation ditch[b]	1-2	0-2	1-2	0-1
Disinfectiond	2-6 (E)	0-1	0-4	0-3
Waste stabilization ponds[e]	1-6 (E)	1-3 (E)	1-4	1-4
Effluent storage reservoirs[f]	1-6 (E)	1-3 (E)	1-4	1-4

a With good design and proper operation the Engelberg guidelines are achievable.
b Further research is needed to confirm performance.
c Including secondary sedimentation.
d Including settling pond
e Chlorination, ozonation
f Performance depends on number of ponds in series
g Performance depends on retention time, which varies with demand.

In meeting biological standards particularly in terms of the removal of helminth eggs, protozoa, bacteria and viruses, waste stabilization ponds are known to be very efficient. These ponds are cheap, easy to maintain and require very little energy. The only draw back with the ponds is that they occupy large land areas. This type of treatment is capable of producing an effluent which meets the recommended Engelberg quality guidelines for unrestricted irrigation.

In many cases a waste stabilization pond system comprising 1-2 days anaerobic followed by a facultative and maturation pond each with a retention time of at least 5 days will be able to produce effluent quality in conformance to the Engelberg guidelines for restricted crop irrigation (Mara and Silva, 1986). For unrestricted irrigation, the effluent of the required quality can be readily produced with a series of 4-6 waste stabilization ponds with an overall retention time of 20 days or more at temperatures above 20°C (Mara and Cairncross, 1988).

Depending upon the variations in the demand of water for irrigation purposes in various seasons, large reservoirs may be used to store the wastewater until it is needed. Such reservoirs will improve the bacterial and helminthic qualities of the stored wastewater. Pathogenic removals in the storage reservoirs may be enhanced by dividing them into compartments, connected in series, to reduce the degree of short circuiting. The retention time in the reservoir may be provided for 10 days during the irrigation season. The effluent being discharged to the reservoir should contain no more than 100 helminth eggs per liter and if it is to be used for unrestricted irrigation, no more than 100,000 faecal coliform per 100 ml during the irrigation season (Mara and Cairncross, 1989). It may be noted that raw domestic sewage typically contains about 10^7 faecal coliform per 100 ml and some 10^3 helminth eggs per liter where helminth infections are prevalent.

INDUSTRIAL REUSE

Industrial reuse of treated wastewater, in particular for cooling purposes, perhaps offers the greatest potential after agriculture. In the USA, for example, 30% of the total wastewater is used for industrial application (Lumbers, 1986).

Criteria

Criteria for once through cooling water are framed by the U.S. Department of Interior (1979) and produced in Table 4.

Table 4: Water Quality Criteria for Once-Through Cooling

Parameter	Value
Alkalinity	500 mg/l as $CaCO_3$
Aluminium	1 mg/l
Calcium	200 mg/l
COD	75 mg/l
Chloride	600 mg/l
Copper	1 mg/l
Hardness	850 mg/l as $CaCO_3$
Iron and Manganese	0.5 mg/l
Magnesium	1 mg/l
Nitrogen (Ammonia)	1 mg/l
Oil	No floating
Oxygen, Dissolved	Present
MBAS	1 mg/l
pH	5.0 - 8.3
Silica	50 mg/l
Suspended Solids	5000 mg/l
TDS	1000 mg/l
Sulphates	680 mg/l
Zinc	1 mg/l

After: US Department of Interior (1979)

Treatment Options

Industrial reuse of wastewaters will essentially require primary and secondary treatment (activated sludge process, biofiltration), followed by one or more of the other methods which include sand filtration, nitrification, chemical clarification, ion exchange and disinfection depending upon the desired effluent quality for the specific use (WHO, 1973).

GROUNDWATER RECHARGE

Groundwater augmentation of untreated or partially treated wastewater and subsequent recovery provides a means of producing a higher quality water suitable for most applications. During groundwater recharge, the wastewater is subjected to Soil-Aquifer Treatment (SAT). The process converts sewage effluents into renovated water which can be collected from aquifer by means of wells or drains. Under certain conditions, the method may prove to be the most appropriate for treating sewage effluents. Artificial recharge can either be made by direct injection or through perculation basins.

Through SAT it is possible to reduce suspended solids, nitrogen, phosphates, fluorides, heavy metals, faecal coliforms, viruses and total organic carbon to acceptable

limits for unrestricted irrigation. The cost of the system is low and it does not require highly trained operation (Pescod and Arar, 1988). For effective results, however, it may be necessary to pretreat the sewage in order to remove suspended solids which decrease basin infiltration rate.
Three countries i.e., France, U.K. and USA have obtained vast experience in this technique. This type of treatment would appear to have a greater role to play in the Near East Region in the future (Pescod and Arar, 1988).

Criteria

For perculating basin water quality, a general standard is recommended by U.S. Department of Interior (1979) and is reproduced in Table 5. It is stated that for direct injection, drinking water quality should be met.

Treatment Options

The quality of water required for direct injection is higher due to the potential of permanently clogging the aquifer. Under such situation full treatment of the wastewater would be required to convert it to the drinking water quality before subjecting it to recharge. Perculation basins, on the other hand, can follow most treatment processes that achieve a fairly low solid content. Effluents treated in conventional plants can be disposed off in perculation basins for the purpose.

The renovated water from the SAT groundwater recharge system will generally meet the public health, chemical and aesthetic requirements for unrestricted irrigation, unless the salt concentration of sewage effluent is very high or there are toxic substances such as born, (Bouwer, 1988).

Table 5: Water Quality Criteria for Groundwater Recharge
(All Units in mg/l except as noted)

Parameter	Value
Arsenic	0.05
Barium	2.00
BOD	10.0
Boron	0.02
Cadmium	0.01
Chromium	0.15
Copper	2.0
Cyanide	0.2
Faecal Coliform (MPN/100 ml)	23
Iron	0.10
Lead	0.05
Manganese	0.10
MBAS	0.50
Mercury	0.01
Nitrogen (Ammonia)	5
(Nitrate)	10
Oil	Virtually free
Oxygen	Present
pH	5.0 - 9.0
Selenium	0.01
Silver	0.10
Solids (Suspended)	10.0
Zinc	10

After: US Department of Interior (1979)

REUSE FOR AQUACULTURE

The term aquaculture refers to the ancient practices of fish culture and the growing of aquatic crops such as water spinach, water chestnut and lotus.

In aquaculture reuse of domestic sewage, emphasis is to be placed on the control of microbial contamination rather than on avoidance of the health hazards of chemical pollution which is of minor importance in the reuse of domestic wastes.

Criteria

Guidelines for microbial quality of treated wastewater were developed by IRCWD in Adelboden, Switzerland in June 1987., These guidelines were based on the rationale that most cultured aquatic macrophytes and some fish are eaten raw in various parts of the world,

especially in Asia. The guidelines therefore recommended zero viable trematode eggs per liter (on an arithmetic mean basis) and less than 10,000 faecal coliform bacteria (on a geometric mean basis). Such stringent trematode guideline is necessary as these pathogens multiply very greatly in their first intermediate host (Mara and Cairncross, 1989).

Tentative guidelines for aquacultural use, analogous to the Engelberg guidelines for agricultural use are presented in Table 6.

Table 6: Tentative microbiological quality criteria for the aqua-cultural use of wastewater and excreta (IRCWD, 1987)

Reuse Process	Viable trematode eggs[a] (arithmetic mean no. per liter or kg)	Faecal coliforms (geometric mean no. per 100 ml or per 100 g) [b]
Fish culture	0	$<10^4$
Aquatic macrophyte culture	0	$<10^4$

a Clonorchis, Fasiolopsis and Schistosoma, Consideration need be given to this guideline only in endemic areas.

b This guideline assumes that there is a one log10 unit reduction in faecal coliforms occurring in the pond, so that in-pond concentration are <1000 per 100 ml. If consideration of pond temperature and retention time indicates that a higher reduction can be achieved, the guideline may be relaxed accordingly.

Treatment

For aquatic macrophyte culture, wastewater should be treated in waste stabilization ponds. Conventional effluents may be treated in a single polishing (maturation) pond of 5 days retention. For fish culture, wastewater should be additionally treated in maturation ponds. The value of faecal coliform assumes a 90% reduction of these bacteria in the pond so that fish and aquatic vegetables are not exposed to more than 1000 faecal coliform per 100 ml. Alternatively, through disinfection a level of less than 1000 faecal coliforms per 100 ml may be achieved in conventional plant effluents.

One treatment option for aquaculture is to connect waste stabilization ponds in series and avoid harvesting from the first pond. (Mara and Cairncross, 1989).

LANDSCAPE IRRIGATION

Treated effluents may, at places, be employed for landscape irrigation, to water public parks and hotel lawns. While doing so care is needed to protect the health of those who come into contact with recently irrigated grass.

Criteria

Water quality for landscape irrigation differs little from that recommended for agricultural irrigation. Table 7 gives the quality requirements for various uses of irrigation water, including landscape irrigation in Arizona (Bouwer, 1989). Mara and Cairncross (1989) recommended effluent of high quality (<100 faecal coliform per 100 ml) to be used to irrigate public parks and hotel lawns. On the other hand, Engelberg report deals irrigation of public parks under quality guidelines for unrestricted irrigation, as indicated in Table 1.

Treatment

To meet the above criteria a series of waste stabilization ponds comprising of anaerobic, facultative and maturation ponds would be required. The size and number of maturation ponds control the number of faecal coliforms in the final effluent of the pond series. Through design process, the optimum combination of maturation pond size and the number required to achieve the desired effluent quality may be determined. Other treatment options include those specified for unrestricted irrigation in Section 2.2.

Table 7: Standards for irrigation with reclaimed wastewater in Arizona (Bouwer, 1988)

	Crop and land use category							
	A	B	C	D	E	F	G	H
pH	4.5-9	4.5-9	4.5-9	6.5-9	4.5-9	4.5-9	4.5-9	4.5-9
Faecal coliforms (CFU/100 ml) Geometric mean (five-sample minimum)	1000	1000	1000	1000	1000	200	25	2.2
Single sample not to exceed	4000	4000	4000	4000	2500	1000	75	25
Turbidity (NTU)	-	-	-	-	-	-	5	1
Enteric virus (PFU/401)	-	-	-	-	-	-	125	1
Entamoeba histolytica ND		-	-	-	-	-	-	-
Ascaris lumbricoids (roundworm eggs)	-	-	-	-	-	-	ND	ND
Common large tapeworm	-	-	ND	ND	-	-	-	-

CFU colony-forming unit
NTU Nephelometric turbidity units
PFU plaque-forming units
ND none detectable, using correct samples and methods and qualified personnel

A Orchards
B Fibre, seed and forage crops
C Pastures
D Livestock watering
E Processed food crops
F Landscaped areas, restricted access
G Landscaped areas, open access
H Crops to be consumed raw.

WASTEWATER REUSE FOR RECREATION

The direct reuse of treated effluents is seldom made for the purpose and invariably such activity comes under the category of indirect use.

Criteria

For recreational purposes, the quality criteria have been suggested by WHO (1973) and recommend no more than 100 coliform organisms per 100 ml in 80% of samples. In addition the wastewater should contain no chemicals that lead to irritation of mucous membrane or skin. It must be mentioned that the current standards for bathing in Europe enforce a faecal coliform concentration of <2000 per 100 ml (Mara and Cairncross, 1989).

Treatment

Primary and secondary treatment (activated sludge, biodfiltration, aerated lagoons, oxidation ditch) followed by sand filtration and disinfection can produce the effluent of desired quality for recreation (WHO, 1973). The quality may further be improved after dilution in naturally occurring stream/river water.

LIVESTOCK WATERING

Another use of treated effluents may be made for livestock watering. Quality standards for such use of wastewater as enforced in Arizona have been presented in Table 7. The quality standard in term of faecal coliform concentration is almost the same as prescribed for unrestricted irrigation in the Engelberg report. As such all treatment options discussed in Section 2.2 for unrestricted irrigation are applicable for the present use.

SUMMARY

1. Reuse of wastewaters for various purposes is becoming essential in most parts of the world.
2. Where such reuse is desired for agriculture, wastewater treatment process selection should consider pathogenic bacteria and helminth eggs removal as a primary objective.
3. For aquaculture, removal of trematode eggs should form the basis of treatment process selection.

4. Water quality criteria for different reuses of treated effluents have been recommended by many agencies including FAO, WHO, IRCWD and US Department of Interior. These must be adhered to with respect to the specific use of the wastewater.
5. Conventional treatment processes, without supplementary disinfection, can not produce effluent that complies with the Engelberg guidelines for unrestricted irrigation. These processes are also not generally effective for helminth egg removals.
6. Waste stabilization ponds, if properly designed and operated can result in effluents suitable for unrestricted irrigation and aquaculture.

REFERENCES

MARA and CAIRNCROSS, S. (1989) "Guidelines for Safe Use of Wastewater and Excreta in Agriculture and Aquaculture". WHO and UNEP, Geneva.

FEACHEM, R.G. et al (1983) "Sanitation and Disease: Health Aspects of Excreta and Wastewater Management." World Bank Studies in Water Supply and Sanitation 3 Chichester, John Wiley, New York.

MARA, D.D. and SILVA, S.A. (1986). "Removal of Intestinal Nematode Eggs in Tropical Waste Stabilization Ponds." Journal of Tropical Medicine and Hygiene. 89 (2): 71-74.

PESCOD, M.B. & ARAR, A (1988). "Treatment and Use of Sewage Effluent for Irrigation", Butterworths, London.

WHO (1973). "Reuse of Effluents: Methods of Wastewater Treatment and Health Safeguards". Report of a WHO Meeting of Experts, Geneva. WHO Technical Report Series No., 517.

FAO (1985). "Water Quality for Agriculture" (Ayers, R. S. and Wescot, D.W.) FAO Irrigation and Drainage Paper No. 29, Rev. 1, Rome, FAO.

US DEPTT. OF INTERIOR (1979). "Water Reuse and Recycling" Vol. 1 & 2 by Culp, Wesner, Culp and Hughes. (Office of Water Research and Technology).

LUMBERS, J. (1986). "Effluent Reuse and Resource Recovery" presented in WHO Inter-country Workshop on Low Cost Water and Sanitation Options. 13-17 Dec., 1986, EMRO, Amman, Jordan.

IRCWD (1985). "Health Aspects of Wastewater and Excreta Use in Agriculture and Aquaculture": The Engelberg Report. International Reference Centre for Waste Disposal, IRCWD News, 23, 11-18.

BOUWER, H. (1988). "Groundwater Recharge as a Treatment of Sewage Effluents for Unrestricted Irrigation" in Treatment and Use of Sewage Effluents for Irrigation, Edit by Pescod and Arar, Butterworths, London.

ARAR, A (1988). "Background to Treatment and Use of Sewage Effluents in Treatment and Use of Sewage Effluents for Irrigation", Edit by Pescod and Arar, Butterworths, London.