IRRIGATION WITH TREATED MUNICIPAL WASTEWATER

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The potential of irrigation water for increasing both food production and the living standards of the rural poor has long been recognized. Irrigated agriculture represents only 13% of the world's total arable land, but the value of crop production from irrigated land is 34% of the world's total. This potential is more pronounced in semi arid and arid areas.
The scarcity of water supplies to meet the needs of population growth and rapid development in agriculture as well as industry have given cause for concern in formulating national development plans in these countries towards the use of unconventional water resources in particular the sewage effluent.
In arid and semi arid areas recycling of water may have a greater impact on future usable water supply than any of the other technologies aimed for increasing water supply. Such as water harvesting, desalting of sea water, weather modification of artificial rainjets.
Treated sewage water can be used for irrigation, industry, recharge of ground water and, in special cases, properly treated wastewater can be used for municipal supply. With careful planning various industrial and agricultural demands may be met by purified water thereby freeing fresh water for municipal use.
In this respect, the reuse of sewage effluent for irrigation purpose seems to be the most promising method.

Abstract

The use of treated sewage water for irrigation ensures the reuse of water resources. Efforts should be focused on maximizing the benefit and minimizing any detrimental effects on people or environment. Sewage irrigation involves complex interactions and it is difficult to assess its long term impact. Appropriate management is of primary importance and requires experience for the accomplishment of its full benefits; routine monitoring is also essential. Further research should be carried out by a mutidisciplinary team. No short-term research programme can provide the answers to questions on the effects of sewage irrigation on environment, and on agricultural productivity.
In this respect National and International Institutions, universities and research centres have an important role in both research and training needed for a safe and efficient wastewater use for agriculture.
The goal of such joint work should be also directed towards the establishment of successful networks categorized according to their purposes which range from information exchange to collaborative planning, implementation and monitoring of research activities in the field of unconventional water resources.

Résumé

L'utilisation des eaux d'égout traitées dans le domaine de l'irrigation assure la réutilisation des ressources en eau. Les efforts devraient viser à maximiser les bénéfices et minimiser les effets défavorables sur la population et l'environnement. L'irrigation par les eaux d'égout entraîne des interactions complexes dont l'impact à long terme est difficile à évaluer. Une gestion appropriée joue un rôle fondamental. Il faut une longue expérience pour que l'on puisse réaliser les meilleurs bénéfices. Un monitorage de routine est également essentiel. Le travail d'équipes multidisciplinaires est une étape importante pour atteindre les objectifs envisagés. Un programme de recherche à court terme ne suffit pas pour donner des réponses aux questions sur les effets de l'irrigation avec les eaux d'égout sur l'environnement et sur la productivité agricole.
Les Etablissements Nationaux et Internationaux, les universités et les centres de recherche jouent un rôle important dans le domaine de la recherche et la formation requises pour aboutir à une véritable utilisation des eaux usées pour l'agriculture.
Le travail d'une telle équipe multidisciplinaire devrait également viser à la réalisation de réseaux classés suivant leurs objectifs: l'échange d'information, la mise au point de plans communs, la réalisation et le monitorage des activités de recherche dans le domaine des ressources en eau non conventionnelles.

Quantity and quality of wastewater

Quantity

Wastewater is composed of 99.9% water and 0.1% of other materials (suspended. colloidal and dissolved solids). In arid and semi-arid areas water resources are so scarce that there is often a major conflict between urban (domestic and industrial) and agricultural demands for water. This conflict can usually only be resolved by the agricultural use of wastewater: the cities must use the fresh water first, urban wastewater after proper treatment-used for crop irrigation. If such a sequance of water resource utilization is not followed, both urban and agricultural development may be seriously constrained with consequent adverse effects on national economic development.
As an example, a city with a population of 500,000 and water consumption of 200 l/d per person would produce approximately 85,000 m^3/d (30 Mm^3/year) of wastewater, assuming 85% inflow to the public sewerage system. If treated wastewater effluent is used in carefully controlled irrigation at an application rate of 6000 m^3/ha/year, an area of some 5000 ha could be irrigated. In addition to this economic benefit, the fertilizer value of the effluent is important. Typical concentrations of nutrients in treated wastewater effluent from conventional sewage treatment processes are given below:

Nitrogen (N)	– 50 mg/l
Phosphorus (P)	– 10 mg/l
Potassium (K)	– 30 mg/l

Assuming an application rate of 5000 m^3/ha/year, the fertilizer contribution of the effluent would be:
N – 250 kg/ha. year
P – 50 kg/ha. year
K – 150 kg/ha. year
Thus, all of the nitrogen and much of the phosphorus and potassium normally required for agricultural crop production would be supplied by the effluent. Further, other valuable micronutrients and the organic matter contained in the effluent will provide additional benefits.

Wastewater constituents and compositions

The physical properties and the chemical and biological constituents of wastewater are important parameter in the design and operation of collection, treatment, and disposal, and in the engineering management of irrigation facilities. The constituents of concern in wastewater treatment and wastewater irrigation are listed in **Table 1**. Composition refers to actual amount of physical, chemical, and biological constituents present in wastewater. The composition of untreated wastewater and the subsequently treated effluent depends upon the composition of the municipal water supply, the number and type of commercial and industrial establishments, and the nature of

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Table 1	***Constituents of concern in wastewater and irrigation with reclaimed municipal wastewater.***	
Constituents	Measured parameters	Reason for concern
Suspended solids	Suspended solids, including volatile and fixed solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater in discharged in the aquatic environment. Excessive amounts of suspended solids cause soil plugging in irrigation systems.
Biodegradable organics	Biochemical oxygen demand, chemical oxygen demand	Composed principally of proteins, carbo hydrates, and fats. If discharged to the environment, their biological decomposition can lead to the depletion of dissolved oxygen in receiving waters and to the development of septic conditions.
Pathogens	Indicator organisms, total and fecal coliform bacteria.	Communicable diseases can be transmitted by the pathogens in wastewater bacteria, virus, parasites.
Nutrients	Nitrogen, Phasphorus, Potassium	Nitrogen, phosphorus and potassium are essential nutrients for plant growth, and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, nitrogen can also lead to the pollution of groundwater.
Stable (refractory) organics	Specific compounds (e.g., phenois, pesticides, chlorinated hydrocarbons)	These organics tends to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of the wastewater for irrigation.
Hydrogen ion activity	pH	The pH of wastewater affects metal solubility as well as alkalinity of soils. Normal pH range in municipal wastewater is 6.5-8.5, but presence of industrial waste can alter pH significantly.
Heavy metals	Specific elements (e.g., Cd, Zn, Ni, Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the wastewater for irrigation.
Dissolved inorganics	Total dissolved solids, electrical conductivity, specific elements (e.g., Na, Ca, Mg, Cl, B)	Excessive salinity may damage some crops. Specific ions such as chloride, sodium, boron are toxic to some crops. Sodium may pose soil permeability problems.
Residual chlorine	Free and combined chlorine	Excessive amount of free available chlorine (>0.05 mg/L. CL^2) may cause leaf-tip bum and damage some sensitive crops. However, most chlorine in reclaimed wastewater is in a combined form, which does not cause crop damage. Some concerns are expressed as to the toxic effects of chlorinated organics in regard to ground water contamination

the residental community. Consequently, the composition of wastewater often varies widely among different countries.

Wastewater quality for irrigation use

Effluent quality criteria based on health requirements

1. Developments of standards and water quality criteria for effluent reuse in irrigation have mainly evolved from a consideration of health risks. In the United States, state health departments or agencies responsible for reuse activities formulate policy or decide on specific projects primarily on the basis of concern about infectious agents, accepting that most other constituents in reclaimed water would pose no immediate substantial harm in the rare case of accidental ingestion. For example the State of California has established standarts (California State Department of Public Health, 1968) which require that the reclaimed water for irrigating food crops at all times must be adequately disinfected and filtered,with median coliform count no more than 2.2/100 ml. A World Health Organisation (WHO, 1973) Committee of Experts on the subject recommended that crops eaten raw should be irrigated only with biologically treated effluent that had been disinfected to achieve a coliform level of not more than 100/100 ml in 80% of the samples.
However, a recent meeting in Engelberg, Switzerland, sponsored by the World Bank and WHO to review the health aspects of wastewater and excreta use in agriculture and aquaculture, concluded that many standarts previously recommended were unjustifiably restrictive and not supported by currently available epidemilogical evidence (International Reference Centre for Wasets Disposal, 1985). It was recommended that WHO should initiate revisions of its 1973 Technical Report No. 517 in collaboration with other interested agencies, such as the World Bank, the FAO and the UN Environment Programme (UNEP). On the basis of the tentative model for the health risks associated with the use of untreated wastewater and excreta, the Engelberg Report included recommendation for the microbiological guality of treated wastewater to be used for agricultural irrigation.
These recommendations were approved by a subsequent meeting of experts and proposed as guidelines for the microbiological quality of wastewater for use in agriculture (Mara and Cairncross, 1987). In the form shown in **Table 2**, these guidelines are expected to be included in a revision of the original WHO Technical Series Report No. 517. For the first time, a guideline for the helminthic quality of treated wastewater is introduced.
The quality guideline for restricted irrigation is intended as production for the health of agricultural labourers but makes no allowance for future improvements in the design and control of irrigation system. Guidelines for unrestricted irrigation are related to the need to protect the health of the consumers of crops (principally vegetables).
2. Apart from effluent quality criteria related to health, there is a need to be concerned about the quality of irrigation water in the term of its effects on the soil and on crops.

Table 2	***Tentative microbiological quality guidelines for wastewater use in agriculture (1).***	
Reuse process	Intestinal nematodes (2) (arithmetic mean no. of viable eggs per litre)	Faecal coliforms (geometric mean no. per 100 ml)
Restricted irrigation (3)		
Irrigation of trees, industrial crops, fodder, crops, fruits trees (4) and pasture (5)	≤1	not applicable (3)
Unrestricted irrigation		
Irrigation of edible crops, sports field and public parks (6)	≤1	≤1000 (7)

(1) In specific cases, local epidemiological, socio-cultural and hydriogeological factors should be taken into account and these guidelines modified accordingly.
(2) *Ascaris, Trichuris* and hookworms.
(3) A minimum degree of treatment equivalent to at least a 1-day anaerobic pond followed by a 5-day facultative pond and a 5-day maturation pond or its equivalent is required in all cases.
(4) Irrigation should cease two weeks before fruit is picxed, and no fruit should be picked off the ground.
(5) Irrigation should cease two weeks before animals are allowed to graze.
(6) Local epidemiological factors may require a more stringent standard (for example, < faecal coliforms/100 ml) for publics lawns, specially hotel lawns in tourist areas.
(7) When edible crops are always consumed well-cooked, this recommendation may be less stringent.
Source: International Reference Centre for Wastes Disposal (1985).

It must be realised that it is not possible to cover all local situations when preparing water quality criteria and the approach has been to present guidelines that stress the management needed to successfully use water of a certain quality. The exact choice in pratice must be at the planning stage, taking account of the specific local conditions. Guidelines for evaluating irrigation water quality applicable to the local conditions encountered are given by the FAO (Ayers and Westcot, 1985).

Bouwer and Idelovitch (1987) provide an excellent and comprehensive coverage of the quality requirements for irrigation with sewage water. Issues other than pathogens are summarized as follows:

— Sewage effluent usually has 200-400 mg/l (T.S.S.) more than the input water from the municipal water supply.

Thus a certain amount of leaching is required. High field irrigation efficiencies associated with small amounts of deep percolation are recommended.

— Sodium and permeability hazard can be assessed by the conventional or adjusted sodium adsorption ratio (SAR). However, an additional surface sealing effect and lower infiltration rates can result from deposition on the soil surface of excessive suspended solids from wastewater.

— Nitrogen is an intriguing constituent of municipal wastewater because of its importance as a fertilizer, its adverse effect when too much is applied, and the various forms in which it can be found in wastewater effluent.

— Phosphorus concentration exceed crop needs when the sewage effluent is from conventional treatment.

Phosphorus leaching is then expected in sandy soils with possible contamination of underlying groundwater.

— Trace elements in small concentration, such as B, Cu, Fe and Zn, are essential nutrients for plant growth but excessive concentration of most trace elements may have toxic effects.

— Little information is available on the behaviour of carcinogenic polynuclear aromatic hydrocarbons (PAB) in soil, and on the effcts of pesticides and surfactants (detergents) is sewage effluent on crops and/or soils. The European project SOVEUR and International Conferances are presently addressing these issues.

Appropriate wastewater treatment for agricultural use

The principal object sewage treatment is to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. Hence the most appropriate wastewater treatment to be used for irrigation is that which will produce an effluent which meets the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirements (Arar,in press).

The design of wastewater treatment plants has usually been based on the need to reduce organic and suspended loads to limit pollution of the environment. Pathogen removal has very rarely been an objective. For reuse of effuents in agriculture, this must

Table 3 ***Estimated costs for 379 m³/day wastewater treatment facilities (in 1986 U.S. dollars) (a), (d).***

System type	Capital costs $ 1,000 (b)	Land area (ha)	Annual energy requirement (1,000 kW.h/year) (c)
1. Low rate biological processes			
Stabilization pond			
Northern climate	531	2.0	0
Southern climate	238	1.2	0
Aerated lagoon	559	0.4	15
2. High rate biological processes			
Oxidation ditch	639	0.4	43
Rotating biological contactors	913	0.6	18

(a) After Reed and Hais with modifications.
(b) Does not include raw wastewater pumping, disinfection or land cost.
(c) Does not include raw wastewater pumping, preliminary treatment, disinfection or sludge treatment and disposal.
(d) Costs are adjusted for 1986 using the Engineering News Record Construction Cost Index.

Table 4 ***Effect of land value on different wastewater treatment processes (a), (b).***

System type	Total present value, in U.S. million dollars at given land value $ 10,000/ha	$ 50,00/ha	$ 100,000/ha
1. Low rate biological processes			
Stabilization pond	4.1	5.9	8.2
Aerated lagoon	6.4	8.3	10.8
2. High rate biological processes			
Oxidation ditch	5.5	6.3	7.3
Biological filter (Trickling filter)	7.4	8.4	9.9

(a) After Arthur with modifications.
(b) Includes capital and operation and maintenance costs for average wastewater flow of 30,000 m³/day and present values at 12 percent discount.

now be of primary concern and treatment processes should be selected and designed accordingly (Hillman, in press). Important issues in the selection of appropriate technologies for small communities and/or developing countries include:
a) Local health concerns;
b) Required effluent quality;
c) Required treatment plant capacity;
d) Initial capital cost;
e) Operation and maintenance cost;
f) Required energy for treatment.
The order of importance of the above factors will vary with each reuse application and use area control.
For example, aerated lagoons and stabilization ponds can be used to treat municipal wastewater adequately for most irrigation purposes. Pond system also have the advantage of acting as a storage reservoir for non-irrigating seasons. A major factor to consider when deciding whether to construct stabilization ponds is the amount of land they require. If little land is available near a wastewater source, untreated or treated wastewater will have to be pumped to stabilization and/or storage ponds in the closest agricultural area. Estimated construction cost for a 379 m^3/day pond system are compared to other forms of biological wastewater treatment in **Table 3**. The land area required for each type of system are also noted. The effect of land value on different wastewater treatment processes is presented in **Table 4**. As shown, although stabilization ponds are often the low-cost option, because they are land intensive, other wastewater treatment options may be more attractive or necessary, particularly for land that carried higher values (Reed and Hais, 1979; Arthur, 1983).
From the data and discussions presented, it can be concluded that low-rate biological processes offer significant economic advantages, especially for small communities.
Furthermore, the operation of low-rate system is not dependent on the availability of highly skilled personel. Also, because significant reductions in pathogenic organisms can be achieved in pond systems, they are well suited for many developing countries where water is short and resources are limited. Where higher levels of treatment are needed, aquatic and soil aquifer treatment systems and other more energy intensive systems maybe the feasible options.

Wastewater application and irrigation methods

Arid and semi-arid countries are attempting more and more to integrate Wastewater in their national water policy and plans. The role of wastewater reuse in planning is discussed by Biswas (1986 In: FAO, 1988). Translation of the national water policy and planning into operational and successful project is the real challenge. Some changes in irrigation system design and operation requirements have been reported by Pettygrove and Asano (1984) and Kay (1988).

When using wastewater as a source of irrigation, the overriding health issue stems from the exposure risk (from direct or indirect contact) of effluent of lower quality. Exposure or contact risk depens among other things on the irrigation scheme and system. A code of practice for desing and installation should guide the whole scheme, starting from wastewater effluent source to the storage system then to the distribution network and the labelled outlets.
The selection of irrigation system and the management of the wastewater application remain our major concern and deserve further attention.

Irrigation methods and technologies

A - Conventional versus improved surface methods

Surface irrigation systems account for 95% of the world's irrigated area. Misuse of water, whether conventional or waste-effluent, causes soil degradation and environmental problems.The FAO Regional Workshop held in Bangkok (FAO, 1990) focused on «Improved Irrigation Systems Performance for Sustainable Agriculture». At the farm level, waterlosses due to deep percolation, seepage, poor distribution efficiency and tailwater could be reduced by improving land levelling and controlling water application. Unproper land levelling always leads to uneven distribution of the water, of suspended and dissolved substances inside the basins and from basin to basin.
Thus localized concentration and deep percolation losses ultimately cause soil and groundwater contamination. Therefore careful levelling should be carried out to avoid surface ponding or stagnant effluent. Under precision grading or levelling (with laser controlled equipment) and with controlled water application by siphons, lay-flat tubes, gated pipes or by automated cablegation or surgeflow system (Humpherys, 1986), the irrigation application efficiency and distribution uniformity can reach 90% (Erieand Dedrick, 1979; Wattenburger and Clyma, 1989 and Aboukhaled et al, 1989). This reduces both deep percolation risks and high localized concentration of nutrients, chemicals, pathogens and heavy metals in the soil. This advances in surface irrigation technologies are still very limited in use in most developing countries.
In all cases, with surfaces methods, agricultural workers should wear protective clothes (shoes and gloves) and irrigation should be restricted to crops other than those consumed raw. Fruit falling on the ground should not be marketed nor consumed and irrigation with wastewater should be stopped about 3 weeks before harvesting.

B - Sprinkler irrigation methods

Health risks from aerosol or small droplets produced by sprinkler irrigation may have been exaggerated in the past (WHO, 1979 and 1989). However, a practical safety measure is to have a buffer strip of land (100 to

300 meters) between the sprinkler-irrigated fields receving treated wastewater and the nearby communities, houses and roads.
Conventional hand operated or portable sprinkler systems should be designed, operated and managed to achieve high storage and application efficiencies and good water distribution uniformity. However, they are relatively labour-intensive. In certain countries sprinkler lines are moved by tractors. This reduces the number of workers involved. Operations during low wind speed is essential to avoid pattern distorsion, unnecessary air drifts and evaporation losses. This condition becomes more critical for wastewater-sprinkler application. Side-roll, center-pivots, LEPA systems (low energy precision application), linear move system, self-propelled giant sprinklers and other automated sprinkler system reduce significantly the number of operators directly involved and thus protection measures can be enforced and controlled more easily. The pathogen types in wastewater and their survival time should guide the management of the system entire soil surface and full crop canopy are wetted by the wastewater effluent. In arid regions, the «sterilization» or «purification» effect of the hot, dry air is expected to be rapid. LEPA systems reduce direct contact, nevertheless the risk is there and consequently it should be assessed and safety measures taken as required.

C - Drip and bubbler systems

Under wastewater application, micro-jet and micro-sprinklers do produce sprays that wet the soil surface and the crops. The workers are exposed to contact risks during their normal agricultural practices. This is less the case with drip and bubbler systems, except during maintanance of the emitter. Bubblers are much less sensetive to clogging than drippers and therefore require less maintanance. The soil wetted area and direct contact risks are greatly reduced in comparison with sprinkler and surface irrigation methods. Wastewater is conveyed through a closed system of tubes and polyethylene laterals from the source of the effluent to the individual plants.
However, the high concentration of suspended solids may interfere with the flow of water in pipes and emitter. Clogging of emitters becames a major concern. On the other hand, laminar flow-types are more sensitive to clogging than turbulant flow-type emitters.
A tentative water classification system was developed to establish criteria by evaluating the clogging potential of a trickle irrigation water source (Bucks et al.,1979). Contributors to clogging were classified in physical, chemical and biological parameters to reflect the effects of suspended solids, chemical precipitation, bacteria and algae. It was stated that: «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 and uneconomical». The clogging mechanisms of filter screens caused by water containing mostly organic parliculate (algae) were studied by Adin and Alon (1986). They conclude that a detachment process of larger particle aggregates leaving the filter screen results in further clogging of drippers.
When wastewater is used as a source of water supply the screen filtration itself should be efficient (200-mesh or 75-micron filters) and should be coupled with media-filtration (gravel and sand filters). In addition more frequent back-washing and maintenance are required to remove the algae, organic and mineral substances. Chlorination and or application of copper sulphate products will be required more than for conventional groundwaters. Adjustment of the pH by acid treatment is only required when chemical precipitations are expected. In all cases suspended solids (SS) should be removed as much as possible before sewage effluenf is used, as high concentration of SS may interfere with the flow of water in pipes, sprinklers, hydraulic structures particularly drip emitters. The plugging potential in drip systems is slight to moderate with 50 to 100mg/litre of suspended solids and becomes very severe for concentrations higher than 100 mg/litre.

D - Sub-surface irrigation

Subsurface irrigation can be achieved either by controlling the depth of an existing water table or by sub-surface irrigation system. 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 aereal organs. As such, sub-surface irrigation system are most suited to wastewater irrigation. However, these system have their limitation.

E - Localized sub-surface irrigation systems

Instead of being placed on the surface, porous seeping tubes (Viaflow), perforated tube (Bi-wall) or drip laterals with slits, orifices or emitters (Geoflow systems) are placed below ground surface in the root zone. They are located at the depth of most active water uptake by the crops. Evaporation losses are reduced to minimum and with proper management, deep percolation beyond the root zone may also be controlled. The high potential of efficient application and uniform water distribution makes these systems attractive and appealing for the safe use of wastewater. Underground systems are vandal proof, less exposed to direct damage during plant protection spraying, harvesting and controlled shallow soil cultivation operations. In addition, the rolling-up of driplines each season is avoided. These advantages are essential for wastewater application as the contact risk is particularly nil. However the management aspect remains a critical issue. The operator does not «see» the emitters and therefore cannot easily provide maintenance when necessary. Double filtration and selection of large orifice and/or self-flushing emitters reduces the problem but does not guarantee a maintenance-free operation. Root intrution into the emitters is other problem that must be carefully considered. The clogging risk remains high with waste water and therefore regular inspection and maintainance are part of good management and operation. ●

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