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Papadopoulos I.

in

Dupuy B. (ed.).
Aspects économiques de la gestion de l'eau dans le bassin méditerranéen

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 31

1997
pages 337-356

Non conventional water resources: present situation and perspective use for irrigation

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SUMMARY - Most countries in the Near East, North Africa and South Europe are arid or semi-arid. They have low rainfall, mostly seasonal and with erratic distribution. Moreover, due to the rapid development of urban and rural domestic water supplies, conventional water resources have been seriously depleted and wastewater reclamation and use for irrigation, among other non conventional water sources, gained increasing role in the planning and development of additional water supplies.
In this respect, in most arid and semi-arid countries, wastewater reclamation and reuse is viewed increasingly as a mean to augment existing and future water resources against the growing demand for water. Reclaimed water is a reliable source even in drought years, and thus is capable to replacing potable water from non-potable water uses. Because of this, wastewater treatment and use for irrigation has been expanded considerably the last few decades. However, wastewaters are unique in composition, often associated with environmental and health risk and their acceptability to replace more conventional or other non-conventional water sources for irrigation is highly dependent whether the health risk and environmental impact are within acceptable levels.
This paper elaborates the benefits and problems associated with non-conventional water resources with more emphasis on wastewaters and provide information on present reuse practices and their future prospective uses for irrigating agricultural crops, within acceptable levels of risk.

Key words: Wastewater, irrigation, environment, health.

RESUME *- La plupart des pays du Proche Orient, d'Afrique du Nord et du Sud de l'Europe sont arides ou semi-arides. Ils ont une pluviométrie faible, essentiellement saisonnière, avec une distribution aléatoire. En outre, étant donné le développement rapide de la fourniture en eau à usage domestique urbain ou rural, les ressources d'eau conventionnelles ont été sérieusement épuisées, et la récupération d'eaux usées et leur utilisation en irrigation, entre autres ressources d'eau non conventionnelles, a joué un rôle croissant dans la planification et le développement de stocks d'eau complémentaires.*

De ce point de vue, dans la plupart des pays arides et semi-arides, la récupération d'eaux usées et leur réutilisation sont considérées, de plus en plus souvent, comme un moyen d'augmenter les ressources en eau existantes et futures, par rapport à la demande croissante. L'eau récupérée est une source fiable, même durant les années de sécheresse, et peut ainsi remplacer l'eau potable pour les utilisations en eau nonpotable. Pour cette raison, le traitement des eaux usées et leur utilisation en irrigation ont connu un développement considérable au cours des dernières décennies. Cependant, la composition des eaux usées est unique, souvent lice à des risques écologiques et sanitaires, et leur acceptabilité, en tant que remplacement pour des sources plus conventionnelles, ou d'autres sources non conventionnelles, dépend étroitement du niveau d'acceptabilité des risques sanitaires et des effets sur l'environnement. La présente communication examine les avantages et les problèmes liés aux ressources en eau non conventionnelles, en mettant l'accent sur les eaux usées; des informations sur les pratiques de réutilisation sont données, ainsi que les perspectives d'utilisations pour l'irrigation des cultures agricoles à l'avenir, à des niveaux de risque acceptables.

Mots-clés: *Eaux usées, irrigation, environnement, santé.*

INTRODUCTION

Land and water development in the Near East and North Africa countries was slow until 1950s. Thereafter, rapid development started and most of the countries introduced national development plans, which accorded the agricultural sector, and particularly irrigation development, top priority. This rapid development of irrigated agriculture has meant that easily accessible water resources, such as rivers and shallow good quality ground water are almost entirely committed. The resulting scarcity of water has caused great concern. In this respect, most of the countries are devising ways to optimize available water supplies and promote the use of nonconventional water resources with particular emphasis on wastewaters reclamation and use for irrigation.

Currently the Near East region is importing more than 50% of its food requirement, and the increased demand for food exceeds the rate of increase in agricultural production. In the Near East region irrigation water is one of the most important factors for increasing agricultural production. The irrigated area in the region comprises only 30% of the cultivated area, but their production amounts to about 75% of the total agricultural production. In large parts of the region, no crops can be grown without irrigation. Twelve countries of the region have less that the minimum required amount of water (750 m^3/capita/year) to sustain their own production of food. There are only four countries in the Near East having more than 2,000 m^3/capita/year. In all other countries of the region scarcity of water is a severe problem (EMENA, 1990).

The situation in North Africa countries is similar to that in Near East and although all the countries of the North Africa have an interest in water reclamation, Tunisia has done the most, making reuse a priority in their national water resources strategy (Bahri, 1991; Asano and Mujeriego, 1992).

Utilization of wastewater for irrigation, without planning, has been practised in many Mediterranean countries for centuries. It has been recognized, however, that wastewater could be a valuable additional water to cope with the scarcity of water resources provided that its use is based on sound planning taking into consideration the risks associated with the use of this water for irrigation. Planned wastewater use may also present to the countries of these regions an opportunity for pollution abatement when it replaces effluent discharge to sensitive surface waters.

POTENTIAL OF WASTEWATER USE IN NEAR EAST AND NORTH AFRICA REGIONS

In the Near East countries (EMENA, 1990), water demand for domestic purposes by the end of the century will exceed the 50% of the available water resources. In some countries the available conventional water resources will be even inadequate to meet the domestic demand. The sectorial water demand in the countries of Near East and North Africa is presented in Table 1 (UNEP, 1991/1992). Evidently at present in twelve countries, more than 20% of the overall available water is used for domestic and industrial purposes. Agricultural irrigation, representing the main demand of the overall water demand, presents a significant opportunity for water reuse, particularly in areas where agricultural sites are near urban areas and can easily be integrated with urban reuse applications. It is important, therefore, for these countries to encourage and promote wastewater collection, treatment and reuse for agricultural production. The importance of reuse could be in compliance with the need to conserve the potable water supply.

Table 1 - *Water use in three different sectors in Near East and North Africa countries (%) (UNEP/FAO, 1991/92).*

Country	Domestic	Industrial	Agriculture
Afghanistan	1	0	99
Algeria	22	4	74
Bahrain	1	0	99
Cyprus	20	2	78
Egypt	7	5	88
Iran	4	9	87
Iraq	3	5	92
Jordan	29	6	65
Kuwait	64	32	4
Lebanon	11	14	75
Libya	15	10	75
Malta	78	8	14
Morocco	6	3	91
Pakistan	1	1	98
Qatar	45	8	47
Saudi Arabia	45	8	47
Syria	7	10	83
Turkey	24	19	57
Tunisia	13	7	80
UAE	11	9	80
Yemen	4	2	94

It is, therefore, imperative that most of the countries seriously consider and promote wastewater treatment and reuse as an integral part of their water resources policy.

It has been anticipated that the quantities of wastewaters will double in most of the countries of the region during the next ten years (EMENA, 1990). It has been reported (UNEP, 1991/92) that at the moment in 12 countries more than 20% of the overall water use is allocated for domestic and industrial purposes. It is therefore important that this wastewater be collected, purified and used for agricultural production. In addition such an approach is considered the most cost-effective and environmentally sound way of disposal.

In Cyprus it has been anticipated that all wastewater generated from the main cities, amounted to about 25 million m^3/year, will be collected and following tertiary treatment to be used for irrigation. In this way it is expected that the irrigated agriculture will be expanded by 8-10% or an equivalent amount of water will be conserved for other sectors.

In Israel reuse up to 1982 amounted to about 25% of the wastewater generated. Since that time several large projects lead to a large increase in water reuse. In 1987 some 230 reclaimed water projects produced about 0.27 x 10^6 m^3/day of reclaimed water from a population of over 4 million people (Argaman, 1989). About 92% of the wastewater was collected by municipal sewers and of this 72 % was reused for irrigation (42%) or groundwater recharge (30%). Reuse constitutes approximately 10 % of the water in Israel, but by 2010 it is projected that reuse will account about 20%, with about 33% of the total water resource allocated to agricultural irrigation.

In Tunisia the effluent from four treatment plants, with a total flow of about 250000 m^3/day is used to irrigate about 4500 ha of orchards, forage crops, cotton, cereals, golf courses and lawns. About 70% of the irrigated area around Tunis uses about 60% of the available wastewater.

BENEFITS AND LIMITATIONS FOR WASTEWATER USE FOR IRRIGATION

As a substitute for freshwater in irrigation, wastewater i important in the overall water resources management. By releasing freshwater sources for potable water supply and other priority uses, wastewater reuse makes a contribution to water conservation and takes on an economic dimension. Moreover, wastewater use schemes, if properly planned and managed, can have positive environmental impact, besides providing increased agricultural yields. Environmental improvement and benefits accrues as a result of several factors (Mara and Cairncross, 1989), including:

- Prevention of surface water pollution, which would occur if the wastewaters were not used but discharged into rivers or lakes. Major environmental pollution such as dissolved oxygen depletion, eutrophication, foaming, and fish kills can be avoided. Planned reuse of wastewater for irrigation prevents such problems and reduces the resulting damages which, if quantified, can partly offset the costs of the reuse scheme.

- Conservation of fresh water resources, or their more rational usage, is especially important in arid and semi-arid areas of the Near East and North Africa countries.

- The use of wastewater for irrigation may lessen the degree of groundwater exploitation, avoiding sea water intrusion in coastal areas.

- The plant nutrients which may eventually pollute environment if raw wastewater or even treated effluent (especially organic matter, nitrogen, phosphorus and potassium) are discharged directly to the environment may serve as plant nutrients when applied as irrigation water. This reduces requirements for artificial fertilizers, with a concomitant reduction in energy expenditure and industrial pollution elsewhere.

- The organic matter added through wastewater irrigation serves as a soil conditioner over time, increasing its water holding capacity. In addition through the soil humus build-up prevention of land erosion and soil conservation could be achieved.

- Desertification and desert reclamation, through the irrigation and fertilization of tree belts.

- Improved urban amenity, through irrigation and fertilization of green spaces for recreation (parks, sports facilities) and visual appeal (flowers, shrubs and trees adjacent to urban roads and highways).

Reuse of wastewater may also have potential adverse impacts on the environment, largely depending on wastewater characteristics, the degree of purification and the method and location of reuse. Soil, groundwater and surface water pollution are among the most important potential disadvantages of the wastewater reuse. However, sound planning and effective management of the irrigation and fertilization regime can minimize these disadvantages.

QUALITY CONSIDERATIONS

Chemical and physicochemical quality characteristics and considerations

The physical properties and the chemical and biological constituents of wastewater are important parameters in the design and operation of collection, treatment and use of the treated effluent (Asano et al., 1984). The magnitude of the problem of sewage effluent and its acceptability for use, therefore, can be assessed properly if its quantity and quality are viewed as integral part of an overall policy that includes water, land use, agricultural production, human health and environmental protection.

Factors that affect the quality of reclaimed water include source water quality, wastewater treatment, treatment reliability, and distribution system design and operation. Industrial source control programs can limit the input of chemical constituents that may adversely affect water quality.

Depending on the use, considerations for water quality criteria include public health protection, use requirements, irrigation effects, environmental considerations, aesthetics, public and/or public perception, political realities (Crook, 1991).

For irrigation uses of reclaimed wastewater, the effects of many chemical constituents are relatively well understood and, therefore, quality limits can be readily determined. The effect of organic constituents in reclaimed water used for crop irrigation requires special attention, particularly if industrial wastes contribute a significant fraction to the wastewater. The health risks associated with microbiological agents are more difficult to assess. This is reflected in widely differing reclaimed water requirements throughout the world.

The constituents of concern in wastewater treatment and wastewater irrigation are listed in Table 2. The constituents and the composition of wastewaters vary widely and depend on the composition of the municipal water supply, nature of the wastes added during use, and the degree of treatment the wastewater is receiving (Asano et al, 1984).

In an integrated approach of treatment and use of the effluent for irrigation the assurance of treatment reliability and avoidance of often and regular monitoring are highly desirable.

In recent guidelines (Ayers, 1977; FAO, 1985; Kandiah 1987; Westcot and Ayers, 1984; Pescod, 1992; FAO/RNEA, 1993), four problem categories, namely salinity, infiltration, toxicity and miscellaneous problems are used for evaluating conventional sources of irrigation water. Irrigation water may be classified into one of three categories namely no restriction, slight to moderate restriction and severe restriction for use.

Biological quality criteria

The health problems associated with the use of raw or partially treated wastewater are well documented (Feachem et. al., 1980; Mara and Cairncross, 1987; 1988; 1989). As a consequence, water reuse standards and guidelines are principally directed at public health protection and are generally based on the control of pathogenic organisms. Several countries in arid and semi-arid regions have developed criteria and/or standards intended to ensure that the use of wastewater does not present unreasonably health risks.

In the 1960's, a microbiological approach to health risks was dominant, concentrating on potential risks and not actual risks, and strict guidelines were set where wastewater was to be used to irrigate crops eaten raw. In California (State of California, Department of Health Services, 1978), this was set at the minimum bacterial (indicator) concentration detectable by routine monitoring (<2.2 coliform/100 ml), and was meant to indicate that the wastewater was pathogen free (Table 3). The coliform levels are not definitive threshold levels justified by rigorous documentation. At the time the regulations were developed, the California Department of Health Services concluded that epidemiological studies of the exposed population at wastewater use sites would be of limited value, and that it was not possible to ascribe numerical risk estimates to reclaimed water with any degree of confidence.

However, the California criteria had particular influence in the formulation of national criteria in several countries of North Africa and Near East. Such an approach created severe problems in some of the counties for accepting reclaimed wastewater for irrigation.

Table 2 *- Constituents of concern in wastewater treatment and irrigation with reclaimed wastewater (Pettygrove and Asano, 1984).*

Constituent	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 is discharged in the aquatic environment.
Biodegradable oganics	Biochemical oxygen demand, Chemical oxygen demand.	Composed principally of proteins, carbohydrates, 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 faecal coliform bacteria	Communicable diseases can be transmitted by the pathogens in wastewater: bacteria, virus, parasites.
Nutrients	Nitrogen, Phosphorus, Potassium	N,P,K are essential crop nutrients. When discharged to the aquatic environment, N and P can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, N can also lead to the pollution of groundwater.
Stable (refractory) organics	Specific compounds. (e.g., phenols, pesticides, chlorinated hydrocarbons)	These organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic to the environment.
Hydrogen ion activity	pH	The pH affects metal solubility as well as alkalinity of soils. Normal range in municipal wastewater is pH=6.5-8.5, but industrial waste can alter pH.
Heavy metals	Specific elements (e.g., Cd, Zn, Ni, Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals.
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 (>5 mg/l Cl_2) may cause leaf-tip burn and damage some sensitive crops. 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 groundwater contamination.

Table 3 *- California treatment and quality criteria for reuse (State of California, Health Department, 1978)*

Type of Use	Total coliform limits	Treatment required
Fodder, Fiber, and Seed Crops Surface Irrigation of Orchards and Vineyards	----------	Primary
Pasture for Milking Animals Landscape Impoundments Landscape Irrigation (Golf Course, Cemeteries, etc.)	23/100 ml	Oxidation and Disinfection
Surface Irrigation of Food Crops Restricted Recreational Impoundments	2.2/100 ml	Oxidation and Disinfection
Spray Irrigation of Food Crops Landscape Irrigation (Parks, Playgrounds, etc.)	2.2/100 ml	Oxidation, Coagulation, Chlorination, Filtration[1] and Disinfection[2]
Non restricted Recreational Impoundments		

[1] Exceptions may be made to the requirements for processed food crops.
[2] The turbidity of filtered effluent cannot exceed an average of 2 turbidity units during any 24- hour period.

In 1973 a WHO Meeting of Experts set guidelines for treatment methods (WHO, 1973). For crops eaten raw, the level practically achievable with chlorination after conventional treatment was set, that is, 100 coliform/100 ml. In the 1989's, it has been realized to be an overly restrictive approach, and efforts were started to gather and assess the epidemiological evidence of health risks.

In 1989, a WHO Scientific Group formulated new guidelines for wastewater use in agriculture and aquaculture which are summarized in Table 4 (WHO, 1989). They are based on preliminary recommendations from Engelberg in 1985 (IRCWD, 1985). The main consideration was given to the fact that in many developing countries the actual health risks associated with human waste use, are associated with helminthic diseases and that the safe use of wastewater in agriculture or aquaculture will therefore require a high degree of helminth removal. For agricultural use, these guidelines introduced a new, stricter approach concerning the need to reduce numbers of helminth eggs (*Ascaris* and *Trichuris* species and hookworms) in effluent to a level of one or less per litter. This means that some 99.9% of helminth eggs must be removed by appropriate treatment processes. Stabilization ponds with certain adequate retention time are particularly effective to achieve this quality but other technologies are also available. These new criteria are of particular importance for the Near East and North Africa countries, suffering from parasites.

Based on current epidemiological evidence, a bacterial guideline of a geometric mean of 1000 faecal coliform per 100 ml for unrestricted irrigation of all crops is recommended. Recently, the international tendency is for more liberal guidelines.

The guideline values given in Table 4 could be modified based on local epidemiological, sociocultural and environmental factors. Greater caution may be justified where there are significant exposed groups that are more susceptible to infection such as people lacking immunity to the local endemic infections.

The WHO guidelines have been accepted by France. Some other European countries are also intended to adopt these guidelines.

An integrated measures approach for public health protection, which appear to be the most promising approach is extensively discussed elsewhere (Blumenthal, 1988; Hespanhol, 1989a; 1989b; Pescod, 1989; Blumenthal et. al., 1989).

Monitoring and evaluation

Due to the characteristics of wastewater, as well as possible long-term effects on the environment and public health, each wastewater reuse project will require its own monitoring program. However, all programs have in common sampling in time and space, so that sufficient information on the quality and quantity of the wastewater, as well as the environment in general, is available before the start of and during implementation of project.

Monitoring must include the quantity and quality of wastewater to be reused, the objects to which the effluent will be applied (crops, soil, aquifer, aquaculture products, recreational lakes, etc.), and the consumer of products irrigated with wastewater.

The aim of monitoring wastewater is to achieve the following (Bastian,1978; Bauer, 1978):

- meet regulatory requirements
- generate detailed research and development information
- serve as an early warning system
- provide data to optimize system operation

Monitoring and evaluation of wastewater reuse projects has to meet certain requirements, relative, to both efficiency and costs (Biswas, 1989). Of great importance is the time during which the given monitoring data are processed and dispatched. This is particularly so with data on public health, when decision makers have to react promptly.

In the Near East and North Africa countries, monitoring is one of the weak points in the overall wast ewater management. In general, inadequate monitoring is practised.

IRRIGATION WITH WASTEWATER

Irrigation with municipal wastewater is a well-established practice in many countries in the Near East, North Africa and Mediterranean European countries. In these countries, often 70 to 90% of applied water is used for agricultural and landscape irrigation. Thus, as the demand for water increases, irrigation with reclaimed wastewater became an important component of the total water resources planning and development.

However, reuse of reclaimed wastewaters may adversely affect public health and the environment. Of particular concern is not only the degree of purification but also selection of the most appropriate methods of irrigation and the water use efficiency by which wastewater is applied at the farmers level. The lower the water use efficiency the higher the possibility to contaminate soil and ground water. In this respect, selection of the irrigation method and scheduling of irrigation are important components in the overall system for efficient and safe use of the reclaimed wastewaters on environmentally sound bases.

In most countries of North Africa and Near East although practising even irrigation with modern irrigation systems they are still suffering by very low water use efficiency. This creates severe environmental problems. In some countries water use efficiency at the farmer level is less than 35%.

Strategy to protect human health and environment

The success of using treated wastewater for crop production depend greatly on adopting appropriate strategies aimed at optimizing crop yields and quality, maintaining soil productivity and safeguarding public health and the environment. Several alternatives are available and a combination of these alternatives will offer an optimum solution for a given set of conditions. The user should have prior information on effluent supply and its quality to formulate and adopt an on-farm management strategy.

Table 4 *- Recommended microbiological quality guidelines for wastewater use in agriculture (WHO, 1989)*[1]

Category	Reuse conditions	Exposed group	Intestinal nematodes[2] (arithmetic mean no. of eggs per liter)	Faecal coliform (geometric mean no. per 100 ml[3])	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[5]	Workers, consumers, public	≤ 1	≤ 1000[4]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, pasture and trees	Workers	≤ 1	No standard recommend ed	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[1] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly.

[2] Ascaris and Trichuris species and hookworms.

[3] During the irrigation period.

[4] A more stringent guideline (≤ 200 faecal coliform per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

[5] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

In the past particular attention has been given on the waste treatment as the only feasible and fully effective measure for the reduction of health risks. However, in most countries of the Near East and North Africa, full treatment of wastes is not feasible or even desirable, due mainly to economic constraints. It is therefore necessary, to consider ways for the protection of human health and environment other than waste treatment, especially where economic constraints are felt (Mara and Cairncross, 1987; Hespanhol, 1990). To achieve this and protect environment and human health, four groups of measures are available (Blumenthal et. al., 1989):

- waste treatment
- restriction of the crops grown
- choice of methods of application of the treated effluent to the crops and
- control of human exposure to the waste, and hygiene

While full treatment prevents excreted pathogens from even reaching the field, crop restriction and human exposure control act later in the pathway, preventing excreted pathogens from reaching the persons concerned, the crop consumers and the agricultural workers. An integrated approach to planning effluent reuse schemes will allow an optimum combination of agrotechnical measures to be selected, depending on the local socio-cultural, institutional and economic conditions.

The crop restriction is a strategy to provide protection to the consuming public (Mara and Cairncross, 1988; Hespanhol, 1990). However, it does not provide protection to farm workers and their families who remain at high risk since they are still exposed to pathogens in the waste on the soil and on the crop. Crop restriction is, therefore, not adequate in its own; it should be complemented by other measures, such as partial waste treatment, controlled application, or human exposure control, and should be considered within an integrated system of control. Partial treatment to the helminthic part of the WHO quality guideline would be sufficient to protect field workers, and cheaper than full treatment. However, the use of raw wastewater for irrigation, still extensively practised in some of Near East and North Africa countries, should be considered unacceptable.

Adopting crop restriction as a means of health and environment protection in reuse projects requires strong institutional framework and capacity to monitor and control compliance with the enforce regulations. Farmers must be advised why such crop restriction is necessary and be assisted in developing a cropping pattern which fully utilizes the constant production of a certain quality treated effluent.

It is evident, however, that crop restriction includes high risk if strong control and legal authorization are not existing.

It is apparent that to control health risks using treated domestic sewage effluent for irrigation, should control first the biological quality. However, to achieve a complete removal of pathogens may be expensive as to be considered an impossible techno-economic proposition. So other measures are necessary to be taken to reduce the risk to an acceptable risk such as the selection of suitable crops for the particular quality of irrigation water. However, this might not be enough because the irrigation method, transportation of such water, various measures against accidental use etc., are equally important factors for reducing health risks. The particular quality of treated effluent to be used for a particular crop can be taken care of by setting quality guidelines (Hespanhol and Prost, 1994). Various other factors affecting health risks however, can not be translated into standards but as a set of rules to be followed. Such rules constitute a code of practice which should be followed with the same diligence as the quality standards.

ENVIRONMENTAL PROBLEMS ASSOCIATED WITH WASTEWATER USE FOR IRRIGATION

Wastewater reclamation and use may contribute to the protection of the environment but inappropriate use could also adversely affect the environment and consequently human health. Problems related to the reuse are interdisciplinary involving a wide range of considerations requiring planned and timely appropriate actions. The specific character of different areas with regard to wastewater quality, demand for water and existing tradition, necessitate specific approaches and solutions which must be adaptable to the existing situation and the level of technology in the country. Among the most important potential adverse effects on the environment with reuse are contamination of soils and water resources (UNEP/FAO, 1991).

Effects on soil and groundwater

Municipal wastewater is likely to contain chemical pollutants. Of particular concern are those that are toxic to man, plants and aquatic biota.
Heavy metals and refractory organics fall into this category although these contaminants currently are not of great concern for most of the countries of the Near East and North Africa. Heavy metals and organics are of more concern for the European Mediterranean countries due to heavy industries.

Effects on soil

A possible long-term problem with wastewater irrigation is building of toxic materials or salinity in the soil. As the unsaturated zone removes chemical pollutants, particularly heavy metals, their concentration and solubility in the soil under certain conditions, will increase with time and, after many years of irrigation, it is possible that toxic levels could develop and be taken by a crop. In this line, most of the European countries have adopted maximum loading by heavy metals per year per area. Such regulations have been also adopted in Tunisia and Cyprus. The problem of soil salinization is common in arid regions where irrigation water is saline and wastewater irrigation could give rise to this effect over a long-term, thereby rendering the land unusable for agriculture.

Soil contamination can occur through wastewater irrigation due to increased rates of salinization and waterlogging, if inadequate leaching is practised. Good irrigation practices are essential to avoid adverse environmental impacts. A compromise between agricultural production and environmental protection is often needed and must be carefully evaluated at the planning stage. Most of the European countries, restricted maximum application of N and P based on environmental impacts rather than on maximum agricultural production. These measures aims at alleviating contamination of groundwater particularly by NO_3-N.

Effects on groundwater

The susceptibility of the population to long term exposure to low levels of toxic chemicals, through the consumption of groundwater into which these materials have leached, is also of concern. However, studies indicate that only negligible amounts of most toxic chemicals (heavy metals) normally move deeper than 30 cm beyond the point of application within the soil.

Under most conditions wastewater irrigation does not present a microbiological threat to groundwater since it is a process similar to slow sand filtration. Most of the pathogens viruses and parasites are retained in the top few meters of the soil, and horizontal travel distances under uniform soil conditions are normally less than 20 m. However under certain hydrogeological situations (limestone formations) microbial pollutants, can be transported for much greater distance and careful investigation is required under such conditions (Lewis et al., 1982).

Of the chemical pollutants, the nitrates are of principal concern with domestic wastes, since they can travel for greater distances, and there is the potential risk that drinking water supplies in the vicinity of wastewater irrigation projects be affected. This contamination by nitrates could be arise particularly when treated effluent is used for recharging underground water, or from seepage and deep percolation from the dams where the treated effluent is collected before being used for irrigation. Water supplies should not be located within, or close to, such wastewater projects. Denitrification during treatment aims at reducing NO_3-N particularly in cases where the treated wastewater is used for recharging ground water.

From wastewater irrigated fields, contamination of underground water could be minimized provided that rational irrigation and fertilization together with appropriate crop selection are practised (Papadopoulos and Stylianou, 1988a; 1988b; 1991). With such an approach it has been found that no penetration of NO_3-N deeper in the soil could be expected.

For land application of wastewaters of concern are also pesticides and trace organic compounds that may be present in wastewaters. The pathways of concern are groundwater contamination and crop uptake. With respect to pesticides there is evidence that some are adsorbed in the soil profile and eventually biodegraded. Concern over trace organics arose with detection of chlorinated hydrocarbons and similar compounds in drinking water supplies. For land treatment systems the concern is that such organic compounds will migrate through the profile and accumulate in drinking water aquifers. Since the most dramatic and severe impact of pollution generally occurs from the wastewater discharged by industry (heavy metals and synthetic organic compounds), source treatment of pollutants should be carried out and, by law, made the responsibility of the industry concerned. On this aspect in most countries of North Africa and Near East no provision has been yet made.

Control measures

In the effort to protect human health and the environment in the past particular attention has been placed on treatment as the only feasible and fully effective measure for the reduction of health risks. However, such an approach emphasizes microbiological criteria, principally the absence of "potential risks" achieved through pathogen removal, and does not fully incorporate the presence of excess and attributable risk. It is necessary to consider ways for the protection of human health and the environment other than wastewater treatment. Taking into consideration economic factors and yet protect the environment and human health, the following measures could be applied:

- adoption and enforcement of wastewater use guidelines and code of practices
- monitoring of wastewater quality
- control of storage and distribution systems
- application control
- crop restriction
- control of the operational procedures
- control of human disposal

To protect environment and public health, without unnecessarily discouraging wastewater reclamation and reuse, many regulations include water quality guidelines as well as requirements for treatment process, sampling and monitoring, wastewater treatment plant operations, and treatment process reliability. The management of the reclaimed water once it leaves the wastewater treatment facility is also an important facet of the overall wastewater reclamation and reuse operation. In order to minimize aesthetic problems and health risks, tight controls are imposed on the delivery and use of the reclaimed wastewaters. The regulations for any specific irrigation use should be based on the expected degree of contact with reclaimed water and the intended use of irrigated crops (Crook, 1985).

LEGAL, SOCIO-CULTURAL, INSTITUTIONAL ASPECTS

Institutional and legal Issues

Although urban sanitation is as important as water supply, in most countries of the Near East and North Africa Regions the sewerage service is far behind the water service. The water distribution system could be considered in general satisfactory, whereas the sewerage systems are mostly not existing or not operating in an appropriate and acceptable way. However, this should not be generalized since in some cities of the region like in Amman, Nicosia and the central sewerage system of Cairo which is in progress, are comparable and even better than the sewerage systems in some developed countries. In this context, in the countries of the region while reasonably strong institutions for managing water supply systems exist, agencies for managing wastewater collection, treatment and disposal are poorly organized and lacking in funds.

Regulatory considerations

To protect public health and environment, without unnecessarily discouraging wastewater reclamation and reuse, many regulations include water quality standards as well as requirements for treatment process, sampling and monitoring, treatment plant operations, and treatment process reliability. Generally, in order to minimize health risks and aesthetic problems, tight controls are also imposed on the delivery and use of reclaimed water (Asano, 1987).

Most of the guidelines and regulations adopted in developed countries were intended to control the quality of the water bodies where the reclaimed water is discharged. In most of these countries, rarely has been considered the reuse aspect as an integral component of the overall treatment system. Because of this, the quality parameters considered as important in these guidelines are BOD_5, SS and faecal coliforms.

The first criteria for wastewater treatment and reuse have been developed and adopted in California (Table 3). These criteria although extremely stringent to a level to be prohibiting for the reclaimed water reuse for irrigation in most of the countries, they have been adopted in a number of countries in the Near East and North Africa as a base for formulating their national criteria and guidelines.

The U.S. Environmental Protection Agency (1992), revised and updated their own guidelines. The primary purpose of these guidelines is to provide information about how to develop effective wastewater reuse programs. They are intended for U.S. utilities and regulatory agencies, that are seeking to establish standards or regulations for the reclamation and reuse of wastewater. They provide, however, useful information although very general, and for the developing countries.

In Jordan, standards for wastewater treatment and reuse in the form of a Martial law had been introduced in 1982. In 1989, a new version of the Martial law was enforced which could be considered more liberal because of the following (Saqer, 1992):

- The crops allowed to be irrigated depend on the quality of effluent.

- Under certain conditions it is allowed irrigation of cereals and even vegetables eaten cooked.

- It allows the irrigation of sport fields and public parks.

By comparing the Martial law with the WHO guidelines, the adopted guidelines in Jordan have also and disadvantages:

- Specifying the number of samples to two per month for monitoring the quality of the reclaimed wastewater is not a useful criterium since two samples could not be considered adequate and representative for the whole month.

- The guidelines are not allowing irrigation of crops eaten uncooked irrespective of the quality of the reclaimed water, whereas they allow irrigation of sport fields and public parks by an effluent having faecal coliforms at 200/100 ml and nematode eggs at < 1/liter.

In Egypt no guidelines yet have been adopted but some existing regulations (Martial law regulation, 1984) prohibit the use of effluent for irrigating crops unless it is treated to the required standards of drained water in the agricultural drains. Irrigation of vegetables eaten raw (uncooked) is prohibited with any effluent quality. It should be stressed that at the moment most of the wastewater plants are discharging their effluents into the agricultural drains that can pollute surface streams and groundwater. The quality parameters required at the moment for such discharge are: Faecal coliforms 5000/100 ml; BOD_5, 60; SS, 80; TDS, 200, NO_3 50 mg/l.

In Lebanon, currently, wastewater treatment and reuse are covered by an old legislation going back to 1930 which prevent deep percolation of wastewater in soil. Moreover, polluted industrial wastewater is not allowed to be discharged to the water bodies without obtaining permission from the appropriate Authorities (Basbis, 1992).

In Syria, guidelines and regulations are currently absent.

In Cyprus more strict standards are adopted than those by WHO with the aim to cover the specific conditions of Cyprus (Table 5). These guidelines are followed by a code of practice as to ensure the best possible application of the effluent for irrigation (Kypris, 1989).

In Israel the use of reclaimed wastewater must be approved by local, regional and national authorities. Effluent used for irrigation must meet water quality standards set by the Ministry of Health. The trend is toward unrestricted use with wider crop rotation, which will necessitate more storage and higher levels of treatment in the future. This trend toward higher levels of treatment, approaching drinking water quality, is being promoted by environmental concerns and by farmers who export produce to high competitive foreign markets (EPA, 1992).

In Tunisia the Water Code, enacted in 1975, prohibits the use of untreated wastewater for irrigating crops eaten raw. More recent legislation covers the regulation of contaminants in the environment, including reclaimed water, and specifies the responsibilities of the Ministries of Agriculture, Public Health and the National Environmental Protection Agency (Bahri, 1991).

France has recently adopted the WHO guidelines. Some other European countries are also oriented toward accepting the same guidelines.

***Table 5** - Wastewater quality standards for irrigation in Cyprus*

Irrigation of:	BOD mg/l	SS mg/l	Faecal coliforms/100ml	Intestinal worms/l	Treatment required
Amenity areas of unlimited access	10* 15**	10* 15**	50* 100**	Nil	Secondary and Tertiary and disinfection
Crops for human consumption. Amenity areas of limited access	A)2 0* 30*	30* 45**	200* 1000**	Nil	Secondary and storage >1 week and disinfection, or Tertiary and disinfect.
	B)-	-	200* 1000*	Nil	Stabilization maturation ponds total retention time>30 days or Secondary and storage >30 days
Fodder crops	A)20* 30**	30* 45**	1000* 5000**	Nil	Secondary and storage >1 week or tertiary and disinfection
	B)-	-	1000*	Nil	Stabilization maturation ponds total retention time >30 days or Secondary and storage >30 days
Industrial crops	A)50* 70**	- -	3000* 10000**	- -	Secondary and Disinfection
	B)-	-	3000* 10000**	- -	Stabilization maturation ponds total retention time>30 days or Secondary and storage >30 days

* These values must not be exceeded in 80% of samples per month
** Maximum value allowed
Note 1. Irrigation of vegetables is not allowed
Note 2. Irrigation of ornamental for trade purposes is not allowed
Note 3. No substances accumulating in the eatable parts of crops and proved to be toxic to humans or animals are allowed in effluent

ECONOMIC ASPECTS

General considerations

The main difficulty in evaluating the economics of wastewater irrigation is the valuation of non financial aspects such as reduction of environmental pollution nuisances or health risks. The other less difficult problem is the allocation of treatment costs between the wastewater producer and the agricultural user. Once these problems have been solved, the analysis of wastewater irrigation can be carried out using standard techniques of economic and social cost-benefit analysis, which are well documented (Shuval, 1990).

The first step in the analysis should begin with the source of the wastewater and estimation of the least-cost disposal options that meet minimum environmental (health, sanitation and pollution) standards. This set of cost estimates provides the logical breakpoint for allocation of costs to the generator of the wastewater. Costs above this amount should be allocated to the wastewater irrigation system. Then assuming that irrigation is economically viable, investigations should be made to assess the demand for irrigation water in areas near the source of the wastewater.

In general there are four areas for reuse:

- Rainfed (seasonal) agricultural areas
- Existing irrigation schemes
- Existing unplanned areas under sewage irrigation
- Marginal lands currently not farmed.

Once land areas for potential reuse have been identified, the cost of conveying wastewater to the area should be estimated in addition to any incremental treatment cost required to make the effluent suitable and acceptable for irrigation.

It should be stressed that a principal difference between the developed countries and the countries of the Near East Region in addressing economic and financial issues concerning reuse arises from the acceptance in the developed countries that the user is responsible for meeting the costs of water and sanitation services. In the countries of the Near East Region, the water in general is provided to the farmers free of charge.

General approach

Economic justification of a reuse project should be based on the costs and benefits of wastewater use. Benefits to be considered may not always be quantifiable. The environmental benefits should be considered as a matter of national policy and it is often difficult to include such complex benefits into economic evaluation (Kalbermatten et al., 1989).

The costs to be considered are:

- treatment costs
- reuse costs, and
- operation and maintenance costs

Treatment costs

Reusing wastewater requires specific treatment which should meet health and environmental protection requirements. Total investment costs for wastewater treatment should include:

- land and site preparation
- civil engineering works
- technology and equipment, including collection system, pipes and pumps and
- pre-production capital costs.

The treatment costs caused by wastewater reuse are necessarily incremental costs, and should be calculated as supplementary costs to the costs of minimum wastewater treatment before discharge to a receiving water. They represent only the marginal treatment costs required to achieve reuse water quality.

Wastewater treatment facilities can be placed at the location of wastewater generation or at the site of irrigation or another user. Both alternatives should be studied and compared to achieve the least-cost solution.

Reuse costs including on-farm costs

Reuse costs can generally be divided into two groups:

- costs of water handling, storage, conveyance, and distribution, and
- on-farm costs

The first group of costs depends, *inter alia*, on the location of the wastewater treatment facilities, whether or not reservoirs are needed to store wastewater until needed for use, and on the size of the irrigated land area.

On-farm costs may include:

- measures to protect public health
- increased levels of hygiene facilities for field workers
- use of lower-valued crops associated with the specific wastewater application
- institutional build-up, including training and facilities

As mentioned before for treatment costs, the reuse and on-farm costs should be calculated as supplementary costs to the costs of production if there were no use of wastewater.

Operation and maintenance costs

Operation and maintenance costs should be calculated for all facilities for wastewater reuse, added to facilities already existing or to those which would be used if there were no wastewater reuse. These facilities may include: wastewater treatment plant, storage reservoirs, wastewater conveyance and distribution facilities, and handling equipment.

Operating costs may include:

- additional energy consumption
- labour
- protective clothing for field workers
- supplementary fertilizer if wastewater is insufficient for proposed crops
- management and overhead costs
- monitoring and testing

Maintenance costs are usually calculated as a percentage of the facilities investment costs.

Benefits

When evaluating wastewater reuse projects, the initial approach is to split all benefits into two groups:

- direct benefits, and
- indirect benefits

Direct benefits are related to the direct use of wastewater in agriculture, aquaculture, industrial or potable water supply, or for other purposes.

In agriculture/aquaculture the benefits can be directly calculated as:

- increase in crop production and yields
- savings in fertilizer costs
- savings in fresh water supply and
- creating job opportunities

Identification and analysis of indirect benefits are complex and sometimes do not lead to the clear quantification needed for cost/benefit ratio estimation.

Wastewater reuse could be an attractive wastewater disposal option in a situation where a high degree of treatment prior to discharge is required for environmental considerations. This is a kind of indirect benefit which could be rather easily estimated, but there are some other indirect benefits related to wastewater reuse which could be taken into account, such as:

- reduced damages to the urban environment
- control of soil erosion
- protection of groundwater
- conservation of fresh water resources
- reduced contamination of receiving surface waters
- secondary recharge of groundwater
- establishment of green areas
- reduced amount of waste
- reduced desertification, etc.

It depends on the kind of wastewater reuse project which of the above mentioned benefits should be considered and the planner should carefully identify, analyze and estimate their impacts.

Cost/benefit ratio and other economic parameters

Broadly speaking, the benefits can be divided into (Dewhurst, 1972):

- those whose value cannot apparently be measured directly in any quantitative terms whatever, and
- those which can be measured in money terms or in some other units.

However, when the benefits are not expressed in the same units, they must be converted into the same units for comparison. Cash is the obvious choice, for it has the special advantage that the benefit in each case can be compared directly with its own investment cost.

There are sometimes items for which no meaningful valuation can be made -especially pure public goods, which can jointly benefit many people and where it is difficult to exclude people from the benefits. Whenever cost/benefit analysis becomes impossible, since the benefits cannot be valued, it is still useful to compare the costs of providing the same benefit in different ways. This is called cost-effectiveness analysis and can be used in evaluating a wastewater reuse project as an alternative solution.

There are two possible ways to apply cost/ benefit analysis:

- Any cost or benefit which is not affected by the alternatives under consideration can be disregarded. In any particular problem of alternative choice decision (wastewater use or not), the costs and benefits that are relevant are just those which will be affected by applying one solution rather that another at that point in time. The cost elements that are relevant vary, however, with the nature of the choice.

- It is often convenient in practice to put down all the costs under each of the alternatives to arrive at the net difference. This means that a lot of the expenses will be entered more than once. The advantage of this routine procedure is that no items of cost are likely to be overlooked. When attention is focused solely on differential items it is possible to overlook one item with disastrous results.

The valuations to be made in any cost-benefit analysis fall under three main heads:

- The relative valuation of different costs and benefits at the time when occur

- The relative valuation of costs and benefits at different points in time

- The valuation of risky outcomes.

After valuation of costs and benefits of a project for each year in the future, an aggregate "present value" should be obtained by using relative values expressed in terms of a time preference rate or a discount rate. An alternative approach is the "rate of return" approach. The rate of return is that rate which sets the present value of the project at 0. In many cases the two approaches give the same answer.

For some projects it is unquestionably the case that the projects impose substantial risk costs. In these cases the present value of returns should be properly adjusted for risk. The most significant risk factor in wastewater reuse projects is the health risk.

Economic evaluation of a project may not be exact because of uncertainty about the future. The most common reasons for uncertainty are inflation, changes in technology, false estimation of the capacities, and the length of construction period. Uncertainty analysis can be undertaken in the form of a sensitivity analysis or probability analysis.

The best solution chosen between alternatives should satisfy the following criteria:

- It should have the highest benefit/cost ratio

- The benefits should exceed those of the next best alternative

- The benefits should exceed its costs.

Cost recovery - pricing

The allocation of water resources affects various, and sometimes conflicting, interests. Farmers may not be aware of the benefits of irrigation with wastewater; industry may resist making investments in wastewater treatment and reuse. Often, resistance is caused by faulty policies in allocating or charging for wastewater resources.

Adequate water pricing is important for cost recovery and to encourage water conservation by the users. Finding an adequate policy for water pricing can control the feasibility of the wastewater reuse scheme. This aspect although important for all water resources, it is of particular importance for managing wastewater reuse. The pollution expected from wastewater reuse will be much higher when irrigation efficiency is low. Even effluents of acceptable quality could adversely affect health and the environment if the application efficiency is low. A prohibiting factor for the low irrigation efficiency could be pricing of the effluent.

Each user should be required to pay for the actual cost of abstracting, treating and transporting water to the point of use and subsequent treatment and discharge after use (Kalbermatten et. al., 1989). Within this broad principle, rules should provide for an equitable sharing of costs and benefits resulting from multiple use of the water. If wastewater reuse results in considerable cost savings to the producer and user, benefits should be shared. If the result is extra cost, to one or the other, then the costs should be shared.

The cost of reused wastewater should be about the same as traditional fresh water, but in some cases it can be different than the price of this water. The decision-maker must determine whether reused wastewater should have an autonomous pricing system or, alternatively, if the "fiction" of a single price should be established.

Identification of financial resources

The allocation of financial resources to a project constitutes an obvious and basic prerequisite, not only for any investment decision but also for present formulation and pre-investment analysis. A feasibility study would serve little purpose if it was not backed by a reasonable assurance that resources are available for a project if the conclusion of the study proved positive and satisfactory. A feasibility study should only be made if financing prospects are fairly good.

Several sources of financing exist, both at the national level and internationally. They can be categorized according to the kind of lending organization:

- international financing organizations (World Bank and Regional Development Banks), which provide loans for initial expenses, setting-up the project and part of the cost for procuring goods and works

- government funding agencies which can co-finance the procurement of goods and works, and

- non-governmental organizations

It must be emphasized that it is important to integrate wastewater reuse into general environmental policy. The ministries, associations and other governmental organizations involved will participate in financing wherever an obvious link is established between the reuse project and the programs designed for environmental control.

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