# AGRICULTURAL WASTEWATER TREATMENT

# CHAPTER 2: APPLICATIONS OF WASTEWATER RESOURCE

## 2.1. Introduction

Water has become a limiting factor in several semi-arid and arid regions of the world, mainly for industrial and agricultural development. Water resources planners are constantly in search of additional sources of water to supplement the limited resources obtainable to their region. Several countries where precipitation is in the range of 100-200 mm a$^{-1}$of the Eastern Mediterranean region, for instance, depend on some small underground aquifers and persistent rivers that are generally located in mountainous regions. Through expensive purification systems drinking water is generally supplied, and over 50 % of the food demand is fulfilled by importation (Van der Hoek et al., 2002; Buechler et al., 2006).

Source substitution seems to be the most appropriate alternative to satisfy less restraining uses, in such conditions, therefore, permitting high-quality waters to be used for local supply. The United Nations Social and Economic Council gave a management policy in 1958 to support this method by stating that "*no higher quality water unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade*" (United Nations, 1958). Low-quality waters like brackish waters, drainage waters and wastewater should be considered as alternative sources for less restraining uses whenever possible (Siebe & Cifuentes, 1995).

Because of the high volumes that are essential agricultural use of water resources has great importance. In the sustainability of crop production in years to come irrigated agriculture will play a main role. Further decrease in the extent of consumable water resources by the year 2000, among competing claims for water for industrial and municipal use, will expressively decrease the availability of water for agriculture. The use of suitable technologies for the advancement of alternate sources of water is, perhaps, the single most suitable method for solving the universal problem of water shortage, in common with developments in the efficiency of water use and with suitable control to decrease water consumption (Scott et al., 2004; Raschid-Sally et al., 2005).

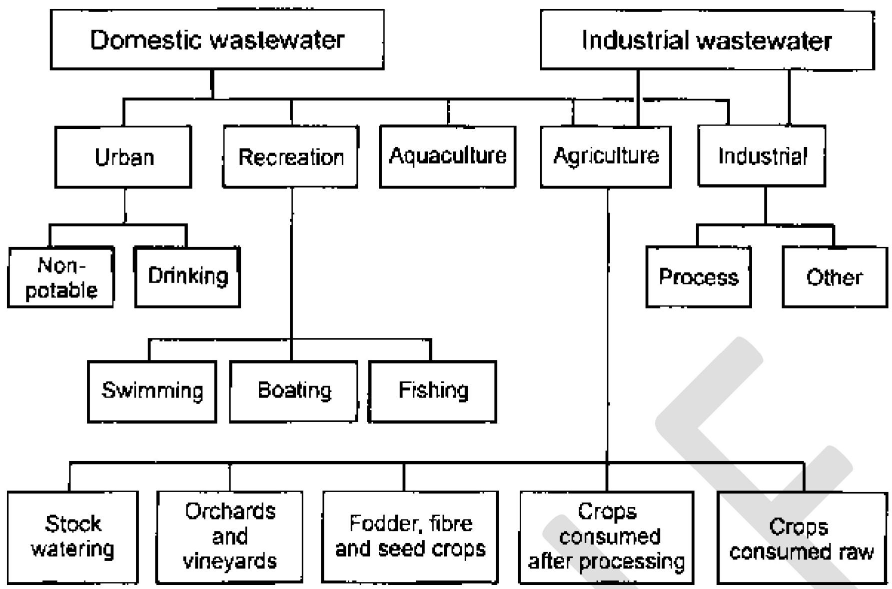


***Figure 2.1. Types of wastewater use (WHO, 1989)***

*[Source: https://www.who.int/water_sanitation_health/resourcesquality/wpcchap4.pdf]*

## 2.2. Types of reuse

Inside the hydrological cycle, water is a renewable resource. The water recycled by natural systems offers a safe and clean resource which is then depreciated by various levels of pollution depending on how, and to what amount, it is used (Angelakis et al., 1999; Lee et al., 2005; Gutterres & de Aquim, 2013). Once used, however, water can be reclaimed and used again for different beneficial uses. The quality of the once-used water and the specific type of reuse (or reuse objective) define the levels of subsequent treatment needed, as well as the associated treatment costs. The basic types of reuse are indicated in Figure 2.1 and described in more detail below (WHO, 1989; Salgot et al., 2006; Becerra-Castro et al., 2015).

### 2.2.1. Agriculture and aquaculture

On an international basis, wastewater is the commonly used low-quality water, mainly for aquaculture and agriculture (Mara et al., 1989; Schwartzbrod & World Health Organization, 1995). This rest of this chapter focusses on this sort of reuse due to the large volumes used, the environmental concerns and the related health risks. Further types of reuse are only discussed briefly in the succeeding sub-sections (Trang et al., 2007a; 2007b).

### 2.2.2. Urban

Reclaimed wastewater, in urban areas, has been used primarily for non-potable applications (Crook *et al.,* 1992) such as:

1. Irrigation of landscaped areas surrounding industrial, commercial, residential and public buildings.
2. Irrigation of recreation centers, public parks, athletic fields, playing fields and schoolyards, and edges and central reservations of highways.
3. Irrigation of golf courses.
4. Fire safety.
5. Ornamental water features and decorative landscapes, like waterfalls, reflecting pools and fountains.
6. Urinal flushing and toilet in industrial and commercial buildings.

The drawbacks of urban non-potable reuse are generally connected with the high costs used in the construction of operational difficulties, dual water-distribution networks and the potential danger of cross-connection. However, costs should be stable with the aids of conserving clean water and eventually eliminating, or postponing, the requirement for the expansion of further sources of water supply (Friedler et al., 2006; Bian et al., 2014).

Drinking urban reuse can be performed indirectly or directly. Indirect drinking reuse contains permitting the reclaimed water (or, on many occasions, raw wastewater) to be diluted and retained in groundwaters or surface before it is treated and collected for human consumption. In several developing countries unintentional, indirect drinking reuse is performed on a large scale, when cities are provided from sources getting considerable volumes of wastewater. Frequently, only common treatment (coagulation-flocculation clarification, disinfection, and filtration) is providing and therefore substantial long-term health effects may be likely from inorganic and organic trace pollutants which keep on in the water supplied (Van Rooije et al., 2005; Capra & Scicolone, 2007).

When the sewage from a wastewater recovery plant is connected to a drinking-water distribution network direct drinking reuse takes place. Treatment expenses are very high since the water has to meet very severe regulations which tend to be gradually restrictive, both in terms of endurable contaminant limits as well as in terms of the number of variables to be monitored (Keraita et al., 2003; Van Rooijen et al., 2010).

Currently, only Namibia is carrying out direct potable reuse throughout dry periods in the city of Windhoek. In 1968 the Goreangab Reclamation Plant built is now being extended to treat about 14,000

$m^3\ d^{-1}$ by 1997 to further increase supplies to the city of Windhoek (Parkinson & Tayler, 2003; Van Der Merwe *et al.,* 1994).

### 2.2.3. Industry

The most communal uses of reclaimed water by industry are (Rehman et al., 2008; Butt & Rehman, 2011):

1. For power stations E\evaporative cooling water.
2. Boiler-feed water.
3. Development of water.
4. Surrounding the industrial plant Irrigation of grounds.

By industry, the use of reclaimed wastewater is a possibly large market in developing as well as developed in and speedily industrializing countries. Industrial reuse is extremely cost-effective for manufacturing where the process does not need water of drinking quality and where industries are situated nearby urban centers where secondary sewage is easily available for reuse (Huibers & Van Lier, 2005; Rehman & Anjum, 2010).

### 2.2.4. Recreation and landscape enhancement

The use of reclaimed wastewater for landscape and recreation improvement ranges from small fountains and landscaped areas to occupied, water-based recreational sites for fishing, boating and swimming (Ou et al., 2006; Kaosol & Sohgrathok, 2012). As for other forms of reuse, the value of the reclaimed water for frivolous uses should be determined by the degree of body connection appraised for each use. , However, in large impoundments, where visual appearance is measured important it may be essential to control nutrients to evade eutrophication (Austin, 2013; Sadi & Adebitan, 2014).

## 2.3. Implementing or upgrading agricultural reuse systems

Land application of wastewater is a viable substitute for increasing resources and an important water pollution control measure in water-scarce areas. The wastewater reuse schemes have many benefits like environmental, economic and health-related (Abdel-Shafy et al.,2011; El Gammal & Ali, 2011). The use of wastewater for irrigation of crops has been significantly increased in the last two decades (Mara and Cairncross, 1989) because of:

1. The costly fertilizers.
2. The increasing shortage of alternate water resources for irrigation.
3. The guarantees that soil damage and health risks are negligible if the necessary protections are taken.

4. The recognition by water resource organizers of the worth of the practice.
5. The socio-cultural reception of the practice.
6. The costly developed wastewater treatment plants desired for discharging wastes to water bodies.

Economic profits can be gained by an increase in production and income generation. Considerable increases in income will increase in areas where cropping was earlier restricted to rainy seasons. The Mesquital Valley in Mexico (see Case Study VII) where agricultural revenue has raised from nearly zero at the turn of the century when waste-water was made accessible to the region, to around 16 million Mexican Pesos per hectare in 1990 (CNA, 1993) is a great example of economic recovery-related with the accessibility of wastewater for irrigation. The practice of wastewater fed aquaculture or excreta has also been a significant source of revenue in many countries like India, Indonesia, Bangladesh, and Peru. The East Calcutta manure fisheries in India, which is provided to the local market is the greatest wastewater use system comprising aquaculture in the world (about 3,000 ha in 1987), yields 4-9 t $ha^{-1}$ $a^{-1}$ of fish, (Edwards, 1992). Economic profits of wastewater/excreta-fed aquaculture can also be found elsewhere (Bartone, 1985; Bartone *et al.,* 1990; Ikramullah, 1994).

| Water Type | Wheat | Cotton | Rice | Moong beans | Potato |
|---|---|---|---|---|---|
| Stabilization pond effluent | 3.45 | 2.41 | 2.98 | 0.78 | 22.31 |
| Raw wastewater | 3.34 | 2.56 | 2.97 | 0.90 | 23.11 |
| Freshwater + NPK | 2.70 | 1.70 | 2.03 | 0.72 | 17.16 |
| Settled wastewater | 3.45 | 2.30 | 2.94 | 0.87 | 20.78 |
| Irrigation water | 8 yrs[1] | 3 yrs[1] | 7 yrs[1] | 5 yrs[1] | 4 yrs[1] |

***Table 2..1 Increases in crop yields (tons ha-1 a-1) arising from wastewater irrigation in Nagpur, India (Shende, 1985)***

To calculate average yield [1]Years of harvest

In several countries' studies have revealed that if wastewater irrigation is provided and accurately managed crop yields can increase. Table 2.1 displays the outcomes of field experiments carried out in Nagpur, India, by NEERI (the National Environmental Research Institute), which examined the effects of wastewater irrigation on crops (Shende, 1985).

Sewages from common wastewater treatment systems, with distinctive concentrations at the usual irrigation rate of about 2 m $a^{-1}$ of 15 mg $l^{-1}$ total N and 3 mg $l^{-1}$ P give application rates of N and P of 300 and 60 kg $ha^{-1}$ $a^{-1}$, individually. Such nutrient efforts can decrease, or even eradicate, the need for viable fertilizers. Along with nutrients, the application of wastewater gives organic matter that works as a soil conditioner, thus growing the capacity of the soil to store water. The rise inefficiency is not the only help since more land can be watered, with the possibility of numerous implanting seasons (Bartone and Arlosoroff, 1987).

From the use of wastewater environmental profits can also be increased. The features that may guide the development of the environment when wastewater is used instead of being disposed of in other customs are:

1. Evading the release of wastewater into surface waters.
2. Preservative groundwater resources in parts where over-use of these resources in agriculture are producing salt interruption into the aquifers.
3. The possibility of soil preservation by the prevention of land erosion and by humus build-up.
4. The visual development of urban situations and recreational actions through fertilization and irrigation of green spaces like sports facilities, parks, and gardens.

Some potential negative environmental effects despite these benefits may arise in association with the use of wastewater. Groundwater contamination is one negative impact. The main problem is related to the nitrate pollution of groundwaters that are applied as a source of water supply. When a highly absorbent unsaturated layer above the aquifer lets the deeper separation of nitrates in the wastewater this may occur. If there is an unsaturated, homogeneous, deep layer above the aquifer that applies to retain nitrate, there is a slight chance of pollution. The uptake of nitrogen by crops may decrease the option of nitrate pollution of groundwaters, but it relies on the amount of uptake by plants and the amount of wastewater application to the crops (Johansson et al., 1996; Gianico et al., 2015).

Another potential negative effect is the accumulation of chemical contaminants in the soil. Relying on the features of the wastewater, prolonged irrigation may guide to the accumulation of inorganic and organic toxic compounds and rises in salinity inside the unsaturated layers. To evade this option irrigation should just use wastewater of mostly domestic origin. Suitable soil drainage is also of essential importance in lessening soil salinization.

Prolonged irrigation may produce habitats for the development of sickness vectors, like snails and mosquitoes. If this is possible, integrated vector control methods should be applied to evade the transmission of vector-borne diseases.

Since wastewater irrigation systems may participate to improved food production indirect health-related aids can happen and thus to improve social conditions, quality of life and health., Potential negative health effects, however, must be taken by institutions managing wastewater reuse schemes and by public health authorities because the consumers of crops, and farmworkers, to some amount, nearby residents can be unprotected to the risk of transmission of infectious diseases.

### 2.3.1. Policy and planning

The use of wastewater establishes a significant element of a water resources strategy and policy. Several nations, mainly those in the semi-arid and arid regions like the Middle Eastern countries, have implemented (in principle) the use of preserved wastewater as a significant concept in their general water resources planning and policy. A sensible wastewater use policy transmutes wastewater from a conservational and health liability to an environmentally and economically sound resource (Kandiah, 1994a; Lyu et al.,2016).

Governments must be ready to control and to establish wastewater reuse inside a broader framework of a national sewage use policy, which itself forms part of a countrywide plan for water resources. cost-allocation and lines of accountability principles should be worked out among the numerous sectors involved, i.e. farmers who will help from sewage use schemes, resident authorities accountable for wastewater treatment and disposal, and the state which is concerned with the establishment of suitable water supplies, the promotion of public and health the safety of the environment. To ensure long-term sustainability, adequate care must be given to the organizational, institutional and social aspects of sewage use in aquaculture and agriculture (Bartone, 1991; Keremane & McKay, 2007).

The planning of wastewater-use projects and programs needs a systematic method. Box 4.1 provides a systematic framework for backing the characterization of basic conditions and the identification of opportunities and restrictions to lead the planning phase of the project (Biswas, 1988).

The government plan on sewage use in agriculture has a decisive effect on the accomplishment of control actions through careful choice of the sites and the crops that may be irrigated with treated sewage. A choice to make treated sewage available to farmers for unlimited irrigation eradicates the possibility of taking benefit of careful choice of sites, crops and irrigation techniques, and thus minimizing the environmental impacts and limiting the health risks. If crop selection is not practical, however, but a government lets unlimited irrigation with sewage in precise controlled areas, public access to those areas can be prohibited (and thus some control is attained). The greatest security against opposing environmental impact and health risk rise from limiting sewage use to limited irrigation on precise areas to which the public has no access (Molina & Melgarejo, 2016).

It has been recommended that the actions involved in formulating plans for sewage irrigation schemes are analogous to those used in most forms of reserve planning, i.e. by the main economic, social and physical dimensions (Cobham & Johnson, 1988). The succeeding key tasks or issues are likely to have an important effect on the last success of sewage irrigation schemes (Biswas, 1988):

1. The managerial and organizational provisions made to manage the resource, to select the sewage-use plan and to apply it.
2. The importance attached to the levels of risk taken and to public health attention.
3. The choice of multiple-use or single-use plans.
4. In appraising alternative reuse proposals, the criteria are adopted.
5. For establishing a forest resource the level of appreciation of the scope.

Implementing a mix of sewage use policies generally, has the advantages of more efficient use of wastewater throughout the year, increased financial security and allowing greater flexibility, while a single-use strategy gives rise to seasonal excesses of sewage for unproductive disposal.

### 2.3.2. Legal and regulatory issues

The usage of wastewater, mainly for irrigation of crops, is related to two major forms of legal issues:

1. Securing incumbency for the operators, mainly regarding rights of access to and possession of waste, and as well as public regulation of its use. land tenure should also be included in the legislation, deprived of which security of access to wastewater is useless (Bazza, 2003).
2. The delimitation of an authorized regime and the formation of the legal status of wastewater for its practice. This may comprise the amendment of the present or the progress of new legislation; the distribution of new powers to current institutions or formation of new institutions; attributing roles of, and relations between, local and national government in the sector; and agricultural legislation, environmental public health and like codes and standards of practice for reuse (Mizyed, 2013).

The following aspects should be addressed for the description of a legal regime for wastewater management (WHO, 1990):

1. Should have a system of certifying of wastewater use.
2. Should have the tenure of wastewater.
3. Should have a description of what is meant by wastewater.
4. Should have the restrictions for the protection of environmental and public health about the planned use of the wastewater, treatment circumstances and final quality of wastewater, and situations for the siting of wastewater treatment facilities.
5. Should have the safety of other operators of the water resources that may be unfavorably affected by the loss of return flows into the system rising from the usage of wastewater.
6. Should have the interface of this legal regime with the general legal regime for the management of water resources, mainly the legislation for environmental and water pollution control and the

legislation governing the sewerage services to the public and the establishment of water supply, with the relevant accountable institutions.

7. Should have the implementation mechanisms.
8. Should have the discarding of the muds which result from wastewater treatment methods.
9. Should have the institutional measures for the administration of related legislation.
10. Cost distribution and pricing.

Monitoring actions are applied at the operative level and enforced through codes of practice, standards, and guidelines. (Angelakis et al., 1999; 2003)

### 2.3.3. Guidelines and standards

To propose guidelines and to make recommendations regarding international health matters is one of the functions of WHO (The World Health Organization). Rules for the safe use of wastewater, is a part of this function are planned to provide guidance and background to governments for risk management decisions related to the protection of public health and the preservation of the environment (Shuval, 1991; Shuval et al., 1997).

In every country, it must be stressed that guidelines are not proposed for direct and absolute application. They are based on epidemiological findings and the state-of-the-art in scientific research and are advisory. They are intended for the formation of a health basis and the health risks and, as such, they give a common background in contradiction of which regional or national standards can be derived (Hespanhol and Prost, 1994).

#### *2.3.3.1. Agriculture*

The Scientific Group on Health Guidelines established the basic criteria for the health safety of the groups at hazard from agricultural reuse systems and suggested the microbiological guidelines for the use of Waste-water in Aquaculture and Agriculture, held in Geneva in 1987 (WHO, 1989) shown in Table 2.2. These guidelines and criteria were the outcomes of a long introductory process and the epidemiological indication existing at the time. They are related to the exposed groups, the reuse conditions, the class of crops and the suitable wastewater treatment systems, to attain microbiological quality (Gurel et al., 2007).

#### *2.3.3.2. Aquaculture*

For fish production the use of excreta or wastewater to fertilize ponds has been linked with numerous infections caused by defaecated pathogens, containing high pathogen concentrations in the digestive tract and incursion of fish muscle by bacteria and the intra-peritoneal fluid of the fish. Field data and imperfect experimental on health effects of wastewater or excreta fertilized aquaculture are presented and, therefore, the Scientific Group Meeting suggested the following uncertain guidelines:

1. To ensure that bacterial invasion of fish muscle is prevented there should be a geometric mean of < $10^3$ fecal coliforms every 100 ml for fish pond water. For pond water in which macrophytes edible (aquatic vegetables) are grownup, the same guideline value should be upheld because in several areas they are eaten raw. This can be attained by treating the wastewater that is supplied to a concentration of $10^3$-$10^4$ fecal coliforms for every 100 ml to the ponds (by assuming that the pond will let one order of magnitude dilution of the incoming wastewater).
2. To avoid infection by helminths such as schistosomiasis, fascialopsiasis clonorchiasis and there should be the total absence of trematode eggs. By stabilization pond treatment this can be readily attained.
3. To avoid infection of fish muscle by the intra-peritoneal fluid of the fish there should be high standards of hygiene during fish gutting and handling.

| **Category** | **Reuse conditions** | **Exposed group** | **Intestinal nematodes[1] (No. of eggs per liter)[2]** | **Fecal coliforms (No. per 100 ml)[3]** | **Wastewater treatment expected to achieve microbiological quality** |
|---|---|---|---|---|---|
| A | Irrigation of crops possible to be eaten uncooked, public parks[4], sports fields | Public, consumers, Workers. | ≤1 | ≤1,000 | To achieve the microbiological quality indicated, or equivalent treatment a series of stabilization ponds is being designed |
| B | Irrigation of fodder crops, industrial crops, cereal crops, trees[5], and pasture | Workers | ≤1 | na | Equivalent helminth and fecal coliform removal or retention in stabilization ponds for 8-10 days |
| C | If exposure of public and workers does not occur localized irrigation of crops in category B | None | na | na | Pre-treatment as vital by irrigation technology, but no below primary sedimentation |

***Table 2.2. Recommended microbiological guidelines for wastewater use in agriculture (WHO, 1989)***

In some specific cases, environmental, socio-cultural and local epidemiological factors should be taken into account, and these guidelines improved consequently.

[1]*Ascaris,* hookworms, and *Trichuris*

[2]The arithmetic means during the irrigation period.

[3]Geometric mean during the irrigation period.

[4]A more strict guideline (200 fecal coliforms per 100 ml) is suitable for public lawns, like hotel lawns, with which the public may have direct contact

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

The chemical quality of treated domestic sewages used for irrigation is also of specific importance. Numerous variables are related to agriculture regarding the quality and yield of crops, the protection of the environment and the preservation of soil productivity. These variables are total electrical conductivity, salt concentration, SAR (sodium adsorption ratio), toxic ions, heavy metals, and trace elements. In FAO (1985) a detailed discussion of this subject is available.

### 2.3.4. Institutional arrangements

Wastewater-use projects at the state level deal with the responsibilities of numerous government agencies and ministries. For minimization of administrative conflicts and satisfactory operation, the following ministries should be involved from the development phase onwards (Mizyed, 2013; Saldías et al., 2016):

1. Ministry of Water Resources: incorporation of wastewater use projects into general water resources management and planning.
2. Ministry of Public Works and Water Authorities: excreta or wastewater treatment and collection.
3. Ministry of Agriculture and Fisheries: supervision of state-owned land; overall project planning; operation and installation of an irrigation setup; aquacultural and agricultural extension, including control of and marketing training.
4. Ministry of Health: disease surveillance and health protection; according to local standards surveillance of sewage quality; responsibility for human exposure control, for example, vaccination, control of diarrhoeal and anaemia diseases (see section 4.4); and health education.
5. Ministry of Planning/Economy/Finance: financial and economic evaluation of projects; and benefit /cost analysis, criteria for subsidizing and financing.

Consistent with national arrangements, other ministries like those focused on rural development, land tenure, environmental protection, co-operatives, and women's affairs may also be involved (Mara and Cairncross, 1989).

Countries starting events including wastewater use for the first time can help significantly from the establishment of an administrative body, an inter-agency technical standing committee for example, which is under the guidance of a leading ministry (Agriculture or Water Resources) and also be responsible for sector development, management, and planning. On the other hand, current organizations may be assigned duty for the sector (or parts of it), for instance, an NFB (National Fisheries Board) might be responsible for the aquacultural use of wastewater and excreta and a NIB (National Irrigation Board) might be responsible for wastewater usage in agriculture. These organizations should then coordinate a team of representatives from the different agencies having sectoral responsibilities. The inter-agency committees have these basic responsibilities (Ormerod, K. J., & Scott, 2013):

1. For wastewater use and monitoring, its execution of a coherent regional or national policy should be developed.
2. Defining the division of responsibilities and the measures for collaboration between the respective agencies and ministries involved.
3. Evaluating the proposed reuse schemes, mainly from environmental protection and the public health point of view.
4. Observing the implementation and promotion of national legislation and codes of practice.
5. A rational staff development policy for the sector should be developed.

Such measures for inter-agency collaboration are even more significant at the state or regional level in countries with a federal or regional administration. The standards and overall framework of waste-use policy may be defined at the national level while the regional body will have to interpret by taking into account local conditions and add to these.

In Mexico CNA (the National Water Commission), is the establishment in charge of the administration, planning, and control of all wastewater use schemes at the national level, which is attached to the Ministry of Water and Agriculture Resources, controls the water resources of the country. Other governmental branches, like the Ministry of Social Development, the Ministry of the Environment and, the Ministry of Health also contribute according to definite interests inside their field of activity. The State government is also integrated at the regional level with the management of local schemes. For example, for the maintenance and operation of the irrigation districts along with monitoring, surveillance and implementation actions in the Mesquital Valley the State of Hidalgo cooperates with the local agency of CNA (the National Water Commission). There is also a strong contribution by the private sector in the Mesquital Valley, dealing with the management of small irrigation units combined into co-operative systems (Fam & Mitchell, 2013).

### 2.3.5. Economic and financial aspects

An economic evaluation of wastewater irrigation projects should have relied on the incremental costs and profits accumulated from the practice. To adjust marginal profits and costs to the current value at a real concession rate and to design the system wisely so that the cost/benefit ratio is > 1 is a procedure that is applied in many projects. Another procedure involves defining the internal rate of return of the project and authorizing that it is viable (Forero, 1993; Nassar et al., 2009).

By comparing with one of the following hypothetical scenarios the financial assessment can be done, each of which is constructed with different costs and benefits (Lu & Leung, 2003):

1. No agriculture and rain-fed agriculture (irrigation) at all.
2. From alternative source irrigation with water without fertilizer application.
3. From alternative source irrigation with water with fertilizer application. *Costs.* In a wastewater irrigation project, the following costs must be considered (Papadopoulos, 1990):
4. Wastewater treatment costs, comprising site and land preparation, equipment and materials, system design, civil engineering works.
5. Irrigation costs comprise of conveyance and distribution, storage water handling.
6. On-farm costs, linked with institutional build-up, including training and facilities, hygiene facilities for field workers, measures for public health protection, and use of minor value crops allied with the precise waste-water application.
7. Maintenance and Operation costs, including protective clothing for field workers, labor, additional energy consumption, monitoring and testing, management and overhead costs, and additional fertilizer if needed.

In the assessment, it is of vital importance that only marginal costs are taken into account. For instance, just the additional costs needed to achieve local sewage standards for reuse should be measured (if they are needed). Costs linked with treatment systems should not be accounted for in the economic appraisal of reuse systems for environmental safety (which would be applied anyway). Likewise, irrigation and on-farm costs that should be measured are only the additional costs accumulated in association with the use of wastewater instead of any other straight source of water (Özerol & Günther, 2005; Qadir et al., 2010).

### 2.3.6. Socio-cultural aspects

Public acceptance of the use of excreta or wastewater in aquaculture and agriculture is affected by religious and socio-cultural factors. For example, in Europe, Africa, and America there is strong hostility to the use of excreta as fertilizer, while in some areas of Asia, mainly in Java, Japan and China, the practice is done frequently and considered ecologically and economical sound (Hespanhol & Prost, 1994; McNeill et al., 2009).

Though, in most areas of the world, there is no cultural hostility to the usage of wastewater, mainly if it is treated. Where other sources of water are not easily obtainable wastewater use is well accepted, or for economic reasons. In some Islamic countries, wastewater is used for the irrigation of crops if the *najassa* (impurities) are removed. However, these results are for economical need instead of cultural preference. The practice of reuse is applied thoroughly only if impure water is changed to pure water (*tahur*) by the succeeding methods (Farooq and Ansari, 1983) according to Koranic edicts: self-purification, elimination of the impurities by the passageway of time or, the addition of pure water in adequate quantity to dilute the impurities or by physical effects (Al-Sa'ed & Mubarak, 2006; Hidalgo et al., 2007).

Because of the extensive inconsistency in cultural beliefs, religious dogmas and human behavior, refusal or acceptance of the practice of wastewater reuse inside a precise culture is not always valid everywhere. A comprehensive assessment of religious beliefs and local socio-cultural situations is always essential as an initial step to applying reuse projects (Cross, 1985; Crook et al., 1992).

## 2.4. Technical aspects of health protection

By the integrated application of four major measures, the health protection in wastewater use projects can be provided: wastewater treatment, human exposure control, wastewater irrigation techniques, and crop restriction and selection.

### 2.4.1. Wastewater treatment

In response to the hostile conditions produced by the discharge of raw effluents to water bodies, the wastewater treatment systems were developed. With this method, treatment is aimed at the pathogens and nutrients, floatable and suspended material, elimination of recyclable organic compounds. The criteria for wastewater treatment, however, intended for reuse in irrigation differ significantly. Whereas it is intended that pathogens are eliminated to the maximum level possible, some of the recyclable organic matter and most of the nutrients obtainable in the raw wastewater need to be upheld (Bauer et al., 2002).

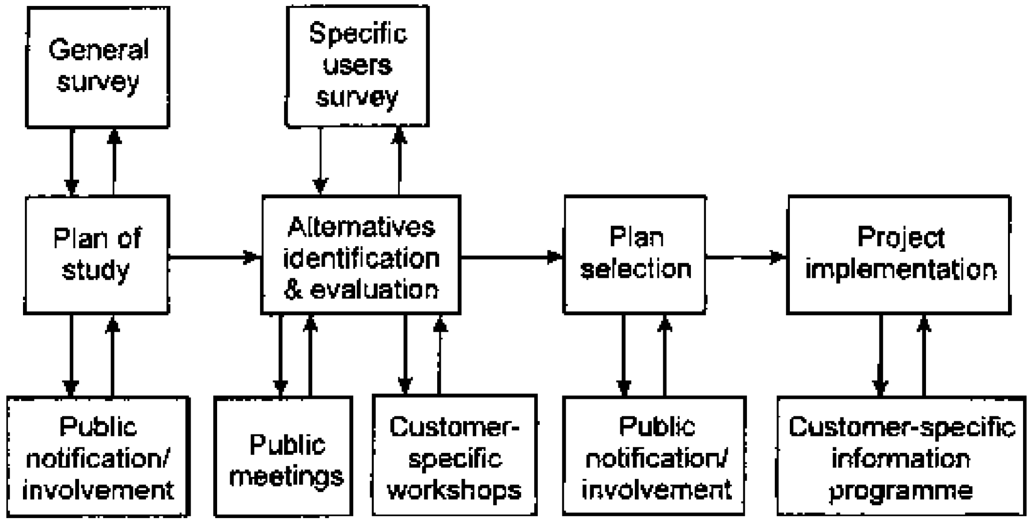


***Figure 2.2. A flow chart illustrating a public participation program (After Crook***

| **Treatment process** | **Removal ($log_{10}$ units) of** | | | |
|---|---|---|---|---|
| | **Bacteria** | **Helminths** | **Viruses** | **Cysts** |
| Aerated lagoon[3] | 1-2 | 1-3 (G) | 1-2 | 0-1 |
| Chemically assisted[1] | 1-2 | 1-3 (G) | 0-1 | 0-1 |
| Primary sedimentation Plain | 0-1 | 0-2 | 0-1 | 0-1 |
| Waste stabilization ponds[5] | 1-6 (G) | 1-3 (G) | 1-4 | 1-4 |
| Biofiltration[2] | 0-2 | 0-2 | 0-1 | 0-1 |
| Oxidation ditch[2] | 1-2 | 0-2 | 1-2 | 0-1 |
| Effluent storage reservoirs[6] | 1-6 (G) | 1-3 (G) | 1-4 | 1-4 |
| Disinfection[4] | 2-6 | 0-1 | 0-4 | 0-3 |

***Table 2.3. Removal of excreted bacteria and helminths by various wastewater treatment systems (Mara & Cairncross, 1989)***

G With proper operation and good design the recommended guidelines are attainable

[1] To confirm performance further research is needed
[2] Including subordinate sedimentation
[3] Including settling pond
[4] Ozonation or Chlorination
[5] Performance relies on the number of ponds in series and other environmental features
[6] Performance relies on preservation time, which differs with demand

| Location of ponds | No. of ponds in series | Effluent quality (fc/100 ml)[1] |
|---|---|---|
| France, Cogolin | 3 | 100 |
| Tunisia, Tunis | 4 | 200 |
| Brazil, Extrabes | 5 | 30 |
| Peru, Lima | 5 | 100 |
| Jordan, Amman | 9 | 30 |
| Australia, Melbourne | 8-11 | 100 |

***Table 2.4. Reported effluent quality from stabilization ponds with a retention time of 25 days (Bartone & Arlosoroff, 1987)***

[1]Faecal coliforms per 100 ml

Table 2.4 recaps the productivity of wastewater treatment systems for the elimination of pathogens, representing where the suggested WHO guidelines for unrestricted irrigation (Category A) can be met. To guide the choice of suitable treatment systems for the use of wastewater in irrigation the succeeding overall comments offer technical support (Hespanhol, 1990).

#### *2.4.1.1. Conventional primary and secondary treatments*

Between $10^7$ and $10^9$ fecal coliform per 100 ml contained by raw domestic wastewater. Conventional treatment systems, like activated sludge, bio-filtration, aerated lagoons, and plain sedimentation, which are intended mainly for the removal of organic matter, are not able to eliminate pathogens to produce sewage that for bacterial quality fulfills the WHO guideline (≤ 1,000 fecal coliforms per 100 ml). Similarly, in helminth removal, they are not normally effective. More adaptive work and research are needed to expand the efficiency of conventional systems in eliminating helminth eggs (Adrados et al., 2014).

#### *2.4.1.2. Waste stabilization ponds*

To provide sewages for reuse in aquaculture and agriculture the ponding systems are the ideal technology, mostly when land is available at normal cost and in warm climates (Mara, 1976; Arthur, 1983; Bartone, 1991). Ponding systems integrating maturation, facultative and anaerobic units, with a general average holding time of 10-50 days (reliant on temperature), can yield effluents that fulfill the WHO guidelines for both helminth and bacterial quality (Sim et al.,2011).

| Sample | $BOD_5$ (mg $l^{-1}$) | Fecal coliforms | Retention time (days) | Intestinal nematode eggs/liter | Suspended solids (mg $l^{-1}$) |
|---|---|---|---|---|---|
| Facultative pond | 45 | $3.2 \times 10^5$ | 5.5 | 1 | 74 |
| Anaerobic pond | 63 | $2.9 \times 10^6$ | 6.8 | 29 | 56 |
| Raw wastewater | 240 | $4.6 \times 10^7$ | | 804 | 305 |
| Effluent from | | | | | |
| Maturation pond No. 1 | 25 | $2.4 \times 10^4$ | 5.5 | 0 | 61 |
| Maturation pond No. 2 | 19 | 450 | 5.5 | 0 | 43 |
| Maturation pond No. 3 | 17 | 30 | 5.8 | 0 | 45 |

***Table 2.5. Performance of five wastewater stabilization ponds (mean temperature 26 °C) (Mara et al., 1983; Mara & Silva, 1986)***

Tables 2.5 and 2.6 show the high confidence through which pond systems can fulfill the World Health Organization (WHO) guidelines and Table 2.6 also illustrates their outstanding capacity for reducing suspended solids and BOD. The Drainage Paper No. 47 *Wastewater Treatment in Agriculture* (FAO, 1985) and FAO Irrigation also gives a good appraisal of wastewater treatment systems which are suggested for wastewater use schemes. Why stabilization ponds are a suitable treatment system for the situations dominant in developing countries the following advantages are the reasons (Ozengin & Elmaci, 2007):

1. High capability to absorb hydraulic and organic loads.
2. No need for energy requirements.
3. Lower maintenance, operation and construction costs.
4. Capability to treat an extensive variety of agricultural and industrial wastes.

#### *2.4.1.3. Disinfection*

Because of the high costs involved and the difficulty of keeping a predictable, uniform and adequate level of disinfection efficacy, the disinfection of wastewater over the application of chlorine has never been entirely effective in practice. Sewages from well functioned conventional treatment systems, a contact time of 30-60 minutes and treated with 10-30 mg $l^{-1}$ of chlorine, have no capacity for eradicating protozoa and helminth eggs but give a good decrease of excreted bacteria. As an operating and well-designed stabilization ponding system will give sewage with < 1,000 fecal coliform per 100 ml and < 1 egg of abdominal nematodes per liter, there is generally no need for disinfection of pond sewages proposed for reuse (Liu et al., 2012).

| **Parameters of evaluation** | **Sprinkler irrigation** | **Furrow irrigation** | **Border irrigation** | **Drip irrigation** |
| --- | --- | --- | --- | --- |
| Capability to keep high soil water potential | Not possible to keep high soil water potential during the growing season | Plants may be dependent on stress among irrigations | Plants may be dependent on water stress among irrigations | Possible to keep high soil water potential through the growing season and lessen the effect of salinity |
| Salt accretion in the root zone with recurrent application | The root zone is not expected to accumulate salts and salt movement is downwards | Salts tend to gather in the edge which could harm the crop | Salts transfer vertically downwards and are not expected to gather in the root zone | Salt movement is outward along the direction of the water movement. A salt wedge is formed among drip points |
| No foliar injury happens under this process of irrigation | Subsequent leaf damage and foliar wetting resulting in poor yield | Severe leaf damage can happen subsequently in significant yield loss | As the crop is planted on the edge no foliar injury | Some bottommost leaves may be affected but the damage is not sufficient to decrease yield |

| | | | | |
|---|---|---|---|---|
| Without significant yield loss suitability to handle brackish wastewater | Poor to fair. Most crops effected from leaf damage and yield are low | Fair to medium. With good drainage and management suitable yields are possible | Fair to medium. Good drainage and irrigation practices can give suitable levels of yield | Excellent to good. Nearly all crops can be grown with very little decrease in yield |

***Table 2.6. Evaluation of common irrigation methods about the use of treated wastewater (Kandiah, 1994b)***

#### *2.4.1.4. Storage reservoirs*

Mostly during specific periods of the year or in the dry season water demand for irrigation arises. Therefore, wastewater planned for irrigation can be stored in large, especially or naturally made reservoirs, which offer more natural treatment, especially in terms of helminth and bacteria removal. Such reservoirs have been used in Israel and Mexico (Shuval, *et al.,* 1986).

To formulate a suitable design criterion for storage reservoirs there are inadequate field data presented, but pathogen elimination relies on the opportunity of having the reservoir separated into compartments and on retention time. The greater the number of compartments in series and the greater the retention time, the greater the efficiency of pathogen removal. Based on data presented from natural storage reservoirs a design recommendation, working in the Mesquital Valley, Mexico, is to give a least hydraulic average withholding time of 10 days, and to accept two orders of magnitude decrease in both helminth eggs and fecal coliform. Thus, so that the WHO guidelines for unrestricted irrigation are achieved, the stored wastewater should contain no more than $10^5$ fecal coliform per 100 ml and no more than $10^2$ eggs per liter, (Vymazal & Kröpfelová, 2008).

#### *2.1.1.1. Tertiary treatment*

To improve the Physico-chemical quality of biological secondary sewages advanced or tertiary treatment systems are used. Numerous unit processes and unit operations, like denitrification, nitrification, and coagulation-flocculation-settling-sand filtration, electro-dialysis, ion exchange, and carbon adsorption, can be applied to follow the secondary treatment to acquire high-quality effluents. For use in developing countries, none of these units are suggested when treating wastewater for reuse, because of the operational costs and high capital involved and the need for very skilled personnel for maintenance and operation (Vymazal, 2009).

If the aim is to improve sewages of biological plants (mainly in terms of helminths and bacteria), for them or aquaculture irrigation of crops, a more suitable option is to add "polishing" ponds as tertiary treatment.

Vertical or horizontal-flow roughing filtration units (which have been used for pre-treatment of turbid waters earlier than slow-sand filtration) may be considered if the land is not accessible. These units, which occupy a comparatively small area and have low cost, are very active for the removal of a substantial proportion of intestinal nematodes and the treatment of secondary sewages. Thorough information on the design, removal efficiencies, and operation of roughing filters can be found somewhere else (Wegelin, 1986; Wegelin *et al.,* 1991).