Agricultural Wastewater Treatment

Edited by:
Akansha Singh

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B	boron
BOD	biological oxygen demand
C	carbon
CC	climate change
Cd	cadmium
CEC	cation exchange capacity
Cl	chloride
CNA	National Water Commission
COD	chemical oxygen demand
CV	climate variability
CWs	constructed wetlands
DALY	disability adjusted life year
DDW	dairy dirty water
EEC	European Economic Commission
EPA	Environmental Protection Agency
ET_c	evapotranspiration
FSH	follicle-stimulating hormone
HAD	heterotrophic-autotrophic denitrification
HCO_3	bicarbonate
LF	leaching fraction
LH	luteinizing hormone
LU	livestock units
MAC	maximum allowable concentration
N_2O	nitrous oxide
Na	sodium
NEERI	National Environmental Research Institute
NFB	National Fisheries Board
NH_3	ammonia

NIB	National Irrigation Board
NLR	nitrogen loading rates
POM	Programmes of Measures
PRB	permeable reactive barriers
PSMs	P absorbing materials
QMRA	quantitative microbiological risk assessment
RIRA	recycled water irrigation risk analysis
S.I	statutory instrument
SAR	sodium absorption ratio
TDS	dissolved solids
THM	trihalomethanes
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
USAID	The United States Agency for International Development
WHO	World Health Organization
ZVI	zero-valent iron

PREFACE

For many centuries, wastewater has been inappropriately used in agriculture, causing potential dangers to the environment and public health. Scientific developments and growing water crisis have compelled the countries to treat and reuse wastewater in agriculture. This practice helps lessen the pressure of water use along with a reduction in environmental pollution. This book presents an overview that discusses the impacts, both negative and positive, of wastewater utilization in the agricultural environment, emphasizing the influence on the soil and aquatic environment. The literature unveils that, until the late 1990s, research studies encouraged the utilization of wastewater for irrigation from a treatment perspective, while suggesting conventional solutions. Nevertheless, more recent studies (2012–2016) show that agricultural reuse considerably affects the texture properties of soil, while also instigating potential modifications of the microbiota and biomass.

Irrigated agriculture yields 33% of the world's crop products and 50% return from worldwide crop production. However, in numerous areas of the world, particularly in arid and semiarid regions the future of irrigation-based agriculture is endangered by existing or projected freshwater shortages. These water shortages essentially result from the ever-growing demand for water by a rapidly growing global population and their elegant lifestyle. Water reuse (recycling), wastewater treatment, and the utilization of treated sewage effluents for industrial agriculture and nonpotable environmental and urban applications can offer a highly efficacious and sustainable approach to exploit water resources in regions afflicted by water shortage. This book essentially focuses on the reuse and treatment of agricultural wastewater to combat the issues of water scarcity and environmental pollution.

The book is divided into eight chapters. All the chapters briefly introduce the readers with fundamental and essential concepts of a topic related to agricultural wastewater treatment. The concepts of agricultural wastewater treatment cannot be understood without grasping the fundamentals related to agricultural wastewater treatment. Chapter 1 discusses the fundamental concepts of agricultural wastewater treatment. Chapter 2 focuses on the applications of wastewater resources. Chapter 3 briefly addresses the essential quality guidelines for agricultural wastewater. Chapter 4 addresses the topic of irrigation using wastewater.

Chapter 5 explains the fundamentals of sewage sludge use in agriculture. On the other hand, Chapter 6 focuses on the benefits and drawbacks of wastewater use in agriculture. Chapter 7 illustrates wastewater irrigation methods in developing countries. Finally, Chapter 8 discusses on-farm wastewater treatment technologies.

This book essentially covers a broad range of areas associated with the utilization and treatment of agricultural wastewater. It can serve as a ready reference for students, teachers, scientists, researchers, agronomists, ecologists, and engineers.

—Author

1

Introduction to Agricultural Wastewaters

CONTENTS

1.1. INTRODUCTION

In many semiarid and arid countries, water is now becoming an increasingly limited resource and managers are forced to take into account sources of water that may be used economically and efficiently to encourage further development. Simultaneously, with the population increasing at a high rate, the requirement for increased production of food is apparent. The prospective for irrigation to increase both the agricultural productivity and living standards of the poor has long been acknowledged. Irrigated agriculture occupies nearly 17% of the total arable land in the world but the yield from this land includes about 34% of the world total. This perspective is even more distinct in arid areas like the Near East Region, where only 30% of the cultivated land is irrigated but it yields around 75% of total agricultural production. In the same area, more than 50% of the food necessities are imported and the increased rate in demand for the food surpasses the rate of an upsurge in agricultural production (Tunney et al., 2000).

Whenever the best quality water is limited, the water of normal quality needs to be taken into account for utilization in agriculture. Although there isn’t any universal definition of marginal/normal quality water, for practical purposes marginal quality water can be defined as the water that owns certain features that can cause issues when it is used for an anticipated purpose. For instance, brackish water is marginal/normal quality water for agricultural utilization due to its high dissolved content of salt, and the municipal wastewater is marginal quality water due to the related health hazards. From the irrigation viewpoint, the utilization of marginal quality water needs more intricate management practices and stringent monitoring processes than when the good quality water is used. This book deals with agricultural utilization of the municipal wastewater, which is mainly domestic sewage but probably contains a ratio of industrial wastes released to public sewers.

Expansion of the urban populations and augmented exposure of the domestic supply of water and sewerage give upsurge to greater amounts of the municipal wastewater. With the current focus on environmental health and the water pollution problem, there is a growing awareness of the necessity to dispose of the wastewaters beneficially and safely. The utilization of wastewater in agriculture could be a vital consideration when the disposal is being intended in semiarid and arid regions. However, it must be recognized that the amount of wastewater accessible in most of the countries will consider only a small proportion of the complete irrigation water necessities. Nevertheless, wastewater utilization will outcome in the upkeep of higher quality of water and its utilization for reasons other than irrigation. As the marginal expense of substitute supplies of best quality water will normally be higher in the water-short areas, it usually makes good sense to integrate agricultural reutilization into water resources and the land use planning (Humphreys et al., 2008).

Properly planned utilization of municipal wastewater improves surface water pollution issues and not only preserves valued resources of water but also takes benefit of the nutrients confined in sewage to cultivate crops. The accessibility of this surplus water near population centers will increase the selection of crops that the farmers can grow. The phosphorus or nitrogen content of sewage may eliminate or reduce the necessities for commercial fertilizers. It is beneficial to consider waste reuse simultaneously as wastewater collection; treatment and removal are planned so that the design of the sewerage system can be improved in terms of waste transport and the treatment methods. The expense of transmission of waste from unsuitably located sewage treatment plants to detached agricultural land is normally prohibitive. Additionally, sewage treatment methods for waste discharge to the surface waters might not always be suitable for agricultural utilization of the effluent.

Numerous countries have comprised wastewater reutilization as a vital dimension of the water resources planning. In the arid areas of the USA and Australia, wastewater is used in agriculture, discharging high-quality supplies of water for potable use. Some countries, for instance, the Kingdom of Saudi Arabia and the Hashemite Kingdom of Jordan, have the policy to reutilization all treated wastewater wastes and have already made substantial development towards this end. In China, sewage utilization in agriculture has advanced quickly since 1958 and over 1.33 million hectares of land are irrigated with sewage effluent now. It is usually accepted that wastewater utilization in agriculture is vindicated on economic and agronomic grounds but care should be taken to lessen adverse health and the environmental impacts.

1.2. FEATURES OF WASTEWATERS

Municipal wastewater is primarily comprised of water together with comparatively small concentrations of dangled and dissolved inorganic and organic solids. Among the organic substances existent in sewage are lignin, fats, carbohydrates, soaps, proteins, synthetic detergents, and their decomposition products, along with several synthetic and natural organic chemicals from the industries. Table 1.1 exhibits the levels of main constituents of the weak, medium, and strong domestic wastewaters. In semiarid and arid countries, water utilization is frequently quite low and sewage inclines to be strong, where consumption of water is 90 l/d per person.

Table 1.1: Main Constituents of Usual Domestic Wastewater

Parameter	**Constituent Concentration, mg/l**		
	Strong	**Medium**	**Weak**
Total solids	1200	700	350
Suspended solids	350	200	100
Dissolved solids (TDS)[1]	850	500	250
Phosphorus (as P)	20	10	6
Nitrogen (as N)	85	40	20
Alkalinity (as $CaCO_3$)	200	100	50
Chloride[1]	100	50	30
BOD_5[2]	300	200	100
Grease	150	100	50

[1] The quantities of TDS and chloride must be increased by concentrations of the constituents in carriage water.

[2] BOD_5 is biochemical oxygen demand at around 20°C over five days and is a measure of biodegradable organic matter in the wastewater.

1.3. PARAMETERS OF AGRICULTURAL IMPORTANCE

The quality of water for irrigation is of particular significance in the arid zones where limits of temperature and low comparative humidity outcome in high evaporation rates, with subsequent deposition of salt which inclines to gather in the profile of soils. The mechanical and physical properties of soil like dispersion of particles, soil structure, the stability of aggregates, and permeability, are sensitive to the kind of exchangeable ions existent in irrigation water. Therefore, when effluent utilization is being planned, various factors associated with soil properties should be taken into account.

Another side of the agricultural concern is the effect of TDS (dissolved solids) in irrigation water on the development of plants. Dissolved salts upsurge the osmotic perspective of soil water and an upsurge in the osmotic pressure of soil solution upsurges the quantity of energy that the plants should expend to consume water from the soil. As an outcome, respiration is augmented and the growth and produce of most of the plants decline gradually as osmotic pressure upsurges. Although most of the plants react to salinity as a function of the total osmotic potential of the soil water, some of the plants are vulnerable to particular ion toxicity.

Many ions which are innocuous or even advantageous at comparatively low concentrations might become harmful to plants at the high concentration, through direct interference with the metabolic procedures or through subsidiary effects on the other nutrients, which may be rendered inaccessible. Morishita (1985) has stated that irrigation with the nitrogen-enriched contaminated water can supply a substantial surplus of the nutrient nitrogen to grow rice plants and can outcome in a substantial produce loss of rice via lodging, failure to mature and increased vulnerability to diseases and pests as an outcome of over luxuriant growth. He further stated that the nonpolluted soil, having nearly 0.4 and 0.5 ppm cadmium (Cd), might yield about 0.08 ppm cadmium in brown rice, whereas only a little upsurge up to 0.82, 1.25, or 2.1 ppm of the soil cadmium can yield heavily contaminated brown rice with 1.0 ppm cadmium (Table 1.2).

Table 1.2: Parameters Utilized in Evaluation of the Agricultural Water Quality

Parameters	**Symbol**	**Unit**
Physical		
Total dissolved solids	TDS	mg/l
Temperature	T	°C
Electrical conductivity	Ec_w	dS/m[1]
Hardness		mg Equiv. $CaCO_3$/l
Color/Turbidity		NTU/JTU[2]
Sediments		g/l
Chemical		
Acidity/Basicity	pH	
Type and Concentration of Anions and Cations:		
Calcium	Ca^{++}	me/l[3]
Sodium	Na+	me/l
Magnesium	Mg^{++}	me/l
Carbonate	CO_3^-	me/l

Bicarbonate	HCO_3^-	me/l
Sulfate	SO_4^-	me/l
Chloride	Cl	me/l
Sodium adsorption ratio	SAR	
Trace metals		mg/l
Boron	B	mg/l[4]
Heavy metals		mg/l
Nitrate-Nitrogen	NO_3-N	mg/l
Potassium	K	mg/l
Phosphate Phosphorus	PO_4-P	mg/l

[1] *dS/m deciSiemen/meter in SI Units.*

[2] *NTU/JTU→ Nephelometric Turbidity Units/Jackson Turbidity Units.*

[3] *me/l→ milliequivalent per liter.*

[4] *mg/l→ milligrams per liter = ppm (parts per million).*

mg/l ~ 640 × EC in dS/m.

Significant agricultural quality of water parameters comprises many particular water properties that are appropriate in association with the produce and quality crops, preservation of the soil productivity, and safeguard of the environment. These parameters primarily comprise certain chemical and physical features of the water. The main wastewater quality parameters of significance from an agricultural point of view are:

1. Total salt concentration;
2. Sodium adsorption ratio;
3. Electrical conductivity;
4. Trace elements and heavy metals;
5. Toxic ions; and
6.` pH.

1.4. AGRICULTURAL WASTEWATERS

In the state of Ireland, farming is a vital national industry that comprises nearly 270,000 people, 6.2 million cattle, 4.26 million sheep, 1.68 million pigs, and around 10.7 million poultry (CSO, 2006). Agriculture uses 64% of Ireland's land area (Fingleton and Cushion, 1999), of which 91% is devoted to silage, hay, and grass, and rough grazing (DAFF, 2003). Grass-based rearing of sheep and cattle dominates the industry (EPA, 2004). Livestock production is linked with external inputs of the nutrients. Phosphorus surpluses gather in the soil (Culleton et al., 2000) and back to phosphorus loss to ground and surface water (Tunney, 1990; Regan et al., 2010). Elevated soil phosphorus status has been recognized as one of the leading phosphorus pressures in Ireland. Schulte et al. (2010). Displayed that it might take several years for elevated soil phosphorus concentrations to be decreased to environmental and agronomical optimum levels. The extent of the delays was mainly associated with the comparative annual P-balance. Whereas the start of reductions in the excessive soil phosphorus levels might be, observed within 5 years, the reduction is a very slow process and might take years to eras to be completed.

Agricultural wastes and specifically dirty water and dairy slurry have been described in this chapter. However, whereas the term waste is commonly used for the materials, it is quite an unlucky label, as it recommends that these materials have no further utilization and are simply a useless by-product of the farming systems that should be managed. Though, given the high contents of nutrients of the materials, it is more suitable for them to be well-thought-out as the organic fertilizers and as such being a respected product for the farmer. With higher and impulsive chemical fertilizer costs in current years, the value of fertilizer replacement in economic terms of the materials is increasing. Thus, the management of agricultural wastes in a way that maximizes nutrient recovery and the fertilizer value to crops must be a top priority within the management plan for the materials.

Nutrient contents and several research areas concerning management, remediation, and control of the nutrients to avoid any loss to the environment are described. The Groundwater Directive, 80/68/EEC (EEC, 1980), The Surface Water Directive, 75/440/EEC (EEC, 1975), the Nitrates Directive, 91/676/EEC (EEC, 1991(a)), the Urban Wastewater Directive, 91/271/EEC (EEC, 1991(b)) and the Drinking Water Directive, 98/83/EC (EC, 1998), combined with current records taken against the State of Ireland by the EU

Commission claiming non-implementation of few sides of the directives has dedicated substantial focus on the environmentally safe discarding of the agricultural wastewaters in Ireland. To address the directives, the WFD (2000/60/EC, 2000) came into power on 22nd December 2000 and was moved into Irish legislation by European Communities Regulations 2003 on 22nd December 2003. 8 “River Basin Districts” were developed in Ireland, south, and north, to accomplish “good status” in all ground and surface water by 2015. The WFD will bring the main changes in the management and regulation of the water resources of Europe. Major changes include:

a) A necessity for the planning of incorporated catchment management plans, with concerns extending over nonpoint and point pollution, land use and water abstraction;

b) The outline of an EU-wide aim of good ecological status for all ground and surface water, except where exceptions for heavily modified water bodies are approved. POM (Programmes of Measures) should be put in place to safeguard ground and surface water whereas being cost-effective and efficient. POM to accomplish at least good ecological status should be executed by the agricultural sector by the year 2012 (Stark and Richards, 2008).

Outcomes from the *Water4all* project recommends that the regulations alone will not accomplish an adequate reduction in the water quality as nitrate accumulates in the soils and long habitation time of the groundwater in aquifers requires a more instant solution (Water4all, 2005; Hiscock et al., 2007). Thus, remediation and control technologies should be an essential part of the procedure for point and scatter pollution from historic or future related nutrient losses. Solutions developed should be integrated struggles within a river basin or catchment.

Good Agricultural Practice Regulations under the Nitrates Directive (European Council, 1991) is presently the major justification measure within the agricultural division to accomplish the objectives of the WFD. The regulations came into upshot in the Republic of Ireland in the year 2006 under S.I (Statutory Instrument) 788 of 2005, and consequently under S.I 378 of 2006, S.I 101 of 2009 and S.I 610 of 2010.

The Nitrates Directive sets restrictions on stocking rates on the farms in terms of quantity of the nitrogen from livestock dung that can be mechanically applied or deposited directly by grazing livestock on the agricultural land. A restriction of around 170 kg N ha^{-1} year^{1} from the livestock dung was set.

Though, the EU Nitrates Committee accepted Ireland's application for the derogation of this restriction to permit grassland-based farmers in order to operate at 250 kg N ha^{-1} year^{-1} from the livestock dungs, with the understanding that derogation won't impose on meeting the necessities of the Nitrates Directive. The present average stocking density on the dairy farms is around 1.81 livestock units (LU) ha^{-1}.The Good Agricultural Practice for Protection of the Waters regulation, S.I 778 of 2005 (Anon, 2005), was established on 1st February, 2006. The most current revision of regulation was published in the year 2010 (Anon, 2010). It constrains the utilization of phosphorus and nitrogen fertilizers, plowing eras, and assists derogation on the livestock intensity. Specifically, it controls farmyard and nutrient management but also inspects avoidance of water pollution from the fertilizers and some activities. The linkage among source and path can be split or damage if the contaminants remain within the boundaries of the farm and are not releasing to subsurface drainage systems, drainage channels, or entering the streams or open ways of water within the boundaries of the farm. These regulations also impose limitations on the land spreading of agricultural wastes.

This tactic looks at current loss and future loss avoidance. There aren't any guidelines in place for remediation or control of the polluted discharges to ground or surface water or future discharges because of incidental losses. Conventionally, agricultural wastes are controlled by land spreading. Following land spreading, the rate of recharge, the hydraulic conductivity of soil, the period of a year of a particular application, the soil depth to the water table or bedrock and the concentration of suspended sediment and nutrients in the wastewater are some defining parameters that decide the movement of nitrate through the soil to the water table. The maximum instant rate of application is five mm/hour and the amount applied must not exceed 50 m^3 per hectare of land per application (ADAS, 1985, 1994; DAFF, 1996) and these endorsements are existent within the best farm management practices. Infiltration depth of rainfall and irrigated water might be assessed when the yearly efficient drainage, number of efficient drainage days, annual precipitation, effective porosity, and a hydraulic load of irrigator are known (Fenton et al., 2009b). This data might then be united with the water table data to scrutinize if surplus nutrients recharge to the groundwater within a particular time frame.

1.5. TYPES OF DAIRY LEFTOVERS AND NUTRIENT CONTENT

In the grassland system, the nitrogen recovery rate of the dairy slurry is highly inconstant due to changes in slurry composition, spreading rates, application methods, climatic, and soil conditions, and slurry nitrogen mineralization rates (Schröder, 2005). In Ireland, nearly 80% of manures produced in the winter season are controlled as slurries comprising 70 g kg^{-1} dry matter, 3.6 g kg^{-1} total nitrogen, and 0.6 g kg^{-1} total phosphorus (Lalor et al., 2010). About 50% of the total nitrogen is in the form of ammonia and can be volatilized as ammonia during the stage storage and subsequent land spreading. Projected organic managed generation of waster for Ireland is given in Table 1.3.

Table 1.3: Projected Agricultural Organic Managed Generation of Waste in 2001

Waste Category	**Waste Generation**	
	Tones Wet Weight	**%**
Water (dairy only)	18,377,550	30.5
Cattle manure and slurry	36,443,603	60.6
Silage effluent	1,139,231	1.9
Pig slurry	2,431,819	4.0
Sheep manure	1,336,336	2.2
Poultry litter	172,435	0.3
Spent mushroom compost	274,050	0.5
Total	60,170,025	

Source: EPA (2004a).

Great discrepancy in the content of nutrient of dairy slurry prevails depending on the type of feed, age of sample when examined, age of the animal, and how the waste is stored and managed (Smith and Chambers, 1993). Seasonal differences in the contents of the nutrient also exist (Demanet et al., 1999). Tables of reported slurry contents of nutrients in Europe prevail (see MAFF, 2000). Such values are quite similar to the dairy slurry concentrations of South America discovered by Salazar et al. (2007). These inclined to be very similar to the other contents of nutrients across Europe discovered by Villar et al. (1979); Scotford et al. (1998a, b) and Provolo and Martínez-Suller (2007). In the state of Ireland, dirty water is produced from dairy parlor water and the machine washings, drizzle, and the water from concreted holding patches. The average production of dirty water per cow is around 49 L^{-1} day^{-1}. Even though dilute, dirty water has adequate nutrients to give upsurge to eutrophication if gone to the water body through excess infiltration or runoff. Implementation of present legislation needs separation of water and fecal matter, therefore diminishing the content of nutrients of dirty water for the land application. As the content of nutrients is decreased and storage and the water charges are high, a substitute solution to the management of dirty water is remediation and reutilization for washing yards

(Fenton et al., 2009).Prediction of the content of nutrients of the agricultural wastewaters will help farmers to precisely calculate the nutrient value of fertilizer replacement of land spread materials and the surplus fertilizer necessities for their crops. Martínez-Suller et al. (2010a) recommend that dry matter content or the electrical conductivity are quick, cheap approaches to approximate the content of nutrient of the wastewaters and dungs.

1.6. FECAL MICROORGANISMS

Waste of agriculture not only carry a threat to the water bodies, but a second main concern is also the existence of pathogenic or antibiotic-resistant bacteria in the animal wastes (Sapkota et al., 2007) and the danger to human health. If handled and treated properly, manure is an efficient and safe fertilizer. However, if improperly treated or untreated, manure might become the main source of pathogens that might contaminate soil, water bodies, and food-stuffs (Vanotti et al., 2007). Animal dung's are known to comprise pathogenic bacteria, parasites, and viruses (Pell, 1997). The pollution of surface waters with the pathogenic microorganisms conveyed from fields to which the livestock slurries and dung have been smeared is a severe environmental concern as it might lead to the humans being exposed to microorganisms through bathing waters (Baudart et al., 2000); drinking water (Skerrett and Holland, 2000); and water used for irrigation of the ready to eat foodstuffs (Tyrel, 1999).

A current study Venglovsky et al. (2009) and Martínez-Suller et al. (2010b) have displayed that animal manure backs considerably to the pathogen loading of soil and therefore runoff to the waterways. Moreover, a current report by EPA in Ireland (Lucey, 2009) outlined the land-spreading of slurry or manure as one of the major sources of microbial pathogens in the groundwater. Further, a report by the Food Safety Authority of Ireland (FSAI, 2008) described that there is a possibility for the transfer of the pathogens to water and food as an outcome of land-spreading of the organic agricultural material.

Research from New Zealand exhibits that dirty water includes fecal microorganisms, which instigate from the dairy cattle excreta. Researchers like Aislabie et al. (2001); McLeod et al. (2003). and Donnison and Ross (2003) have displayed the transfer of bacterial indicators, *Campylobacter jejuni,* and fecal coliforms through the soil. The Pathogen Transmission Routes Research Program in New Zealand exhibited that substantial feces pollution arose through the removal of feces by the grazing animals with entrance to waterways. Fencing and execution of buffer strips were suggested as mitigation measures in order to avoid such losses (Collins et al., 2007). The existence of fecal pointer organisms is used to recognize waters obstructed by fecal matter from the mammals. Indicators of fecal pollution like *E. coli* are broadly used as they are fecally particular and supposed to not last for more than four months post excretion (Jamieson et al., 2002). Recent research has displayed that *E. coli* can last for long periods in the temperate soils (Brennan et al., 2010) and assist in high exposures in the drainage water from agricultural soils. *E. coli* were particularly linked with poorly drained soils because of the greater perseverance of superior flow channels and the anaerobic micro sites where they may survive. Therefore, the existence of *E. coli* in the waters might not indicate current pollution by fecal matter but can be because of the historical pathogen deposition. Several treatment systems might be used to treat livestock wastes and decrease or remove viral, eukaryotic, and bacterial pathogens. Examples comprise biogas producing anaerobic digestion, aeration, composting, storage under a range of redox conditions, and anoxic lagoons, all have been studied by Topp et al. (2009).

1.7. CURRENT PRACTICES OF MANAGEMENT FOR THE AGRICULTURAL WASTEWATERS

The Nitrates Directive and increasing prices are now compelling better utilization of nutrients in the slurry. Research in the United Kingdom (Misselbrook et al., 1996, 2002; Smith and Chambers, 1993; Smith et al., 2000) comprises improving N retrieval from slurry by inspecting the effects of spreading approach and timing and decreasing ammonia (NH_3) losses from the slurry by assessing splash plate versus substitute techniques like trailing hose or trailing shoe slurry application methods. The average reduction of these approaches changes and differs when arable or grassland applications are considered (Smith and Misselbrook, 2000; Misselbrook et al., 2002). Current research in Ireland trails similar patterns (Ryan, 2005). Emissions of ammonia concerning the trailing shoe vs. splash-plate and consequent N uptake by sward are being examined in Irish grasslands (Lalor and Schulte, 2008). Farm management strategies designed at avoidance of nutrient loss to the water have currently been reviewed by Schulte (2006). The Nitrates Directive regulations enforce restrictions to N and phosphorus inputs onto tillage farms and livestock. Dairy and cattle farming systems are needed to make more effective utilization of nutrients. International experience recommends that substantial gains in nutrient effectiveness can generally be made by escalating the usage of N in slurry. Lalor (2010) recommended N-utilization effectiveness from the slurry as low as 5% under prevailing practices, while international literature recommends that there is a possibility to raise effectiveness to 40–80%. Despite the comparatively low utilization in practice, the regulations of Nitrates set an NFRV (nitrogen fertilizer replacement value) target of 40%, presenting a substantial challenge for the grassland sector. Furthermore, the ceiling to inputs of nutrient enforced under the Directives of Nitrates made it very difficult for several livestock farmers to endure to admit pig slurry as the fertilizer onto the farm. In Ireland, as an outcome, the prospective for the customary practice of scattering slurry on the grasslands has generally been reduced significantly. Returning pig slurry to the arable land permits a more closed cycle of nutrients to operate, as cereal grains establish a substantial ratio of a diet of the pigs. However, this establishes a main logistic challenge where pig farms and arable land aren’t closely located (Lalor et al., 2010).

In Irish research, cattle slurry application on the grassland displays that the NFRV in a year of application is influenced by application approach and timing. Cattle slurry applied with splash-plate had an NFRV of nearly 21% in April and 12% in June. Application using trailing shoe escalated the NFRV to 30% in April and 22% in June. Changing the timing of application from summer to spring with prevailing splash-plate machinery is the cost-effective method for improving NFRV. Approximately 4% of the entire slurry N applied was recuperated in the 2nd year after application. For frequent applications over many years, models specify that the maximum growing remaining recovery would be 12 to 14% of the yearly slurry N application rate. It would take nearly ten years of recurrent slurry applications for residual N discharge to reach the maximum level (Lalor et al., 2010).

In Ireland, besides methods of land application, dirty water irrigation using center pivotal irrigation systems is common (Figure 1.1). The suggested irrigation rates must not surpass 5 mm hr^{-1}. Strict guidelines for safe utilization are in place. Application timing of the dirty water must take the status of soil physical properties and soil moisture into account (Houlbrooke et al., 2004). Two pond systems are used in several countries decreasing the biological oxygen demand (BOD) and suspended contents of solids. A restriction is that the nutrient remains unchanged and must be land spread with probable environmental consequences (Figure 1.2).

Figure 1.1: Rotational center pivot sprinkler system used for dairy dirty water irrigation.

Source: www. Teagasc.ie.

Figure 1.2: Slurry tanker having a system of trailing shoe applications made by Craggs et al. (2004), and could be a substitute on dairy farms.

Source: https://www.intechopen.com/books/waste-water-evaluation-and-management/agricultural-dairy-wastewaters.

Houlbrooke et al. (2006) exhibited that individual irrigation systems with low recurrent irrigation rates could be used without nutrient losses. To facilitate the low irrigation rate, augmented storage is required on a farm. Modified low irrigation lines have also been examined, the position of which might be changed through the utilization of the quad-bike system. Bolan and

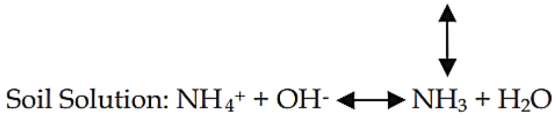
Swain (2004) reviewed problems and novelties in land application of the farm wastes in New Zealand and displayed that research should focus on enhanced systems to convert dung based wastes into some valuable but also environmentally friendly products.

An alternative dung management system in some of the countries/states is anaerobic digestion. Manures are an outstanding source of organic materials for the anaerobic digestion and production of biogas. Co-digestion of the agricultural wastes with manure sludge's can further enhance the production of methane in anaerobic digesters (Ward et al., 2008).

1.8. ENVIRONMENTAL INFLUENCE OF AGRICULTURAL WASTEWATERS

Agricultural wastewaters can comprise N, K, S, P, C, pathogenic microorganisms, and a variety of some other micronutrients. Nutrients returned to the agricultural soils via land-spreading are significant for nutrient effectiveness on the farms and decreasing dependence on inorganic fertilizers. A land application must be at rates that deliver nutrients for the growth of crops and at a time when the nutrients are needed. The addition of surplus nutrients at times of decreased crop demand can upsurge the probable for losses of nutrients like N and P, which assist to surface water eutrophication and can also lead to contamination of drinking waters. Moreover, land application to the wet soils can trigger to escalated emissions of the greenhouse gases like nitrous oxide (N_2O).

Land-spreading of dairy wastewaters and slurry has been linked with ammonia volatilization to the atmosphere. Application of the ammoniacal nitrogen to soils in the wastewater upsurges the soil solution NH_4^+ concentration.



Ammonia volatilization from the soil lowers the pH of the soil right under the wastewater. Further soil pH reduction can take place when the volatilized NH_3 is deposited again and nitrified. Agriculture is the major emitter of the NH_3 to atmosphere accounting for nearly 80% of entire global emissions (Stark and Richards, 2008) and is anticipated to reach around 109 Tg N yr^{-1}

by the year 2050. Once in the atmosphere, NH_3 can combine readily with SO_4^{2-} and NO_3 in the acid cloud droplets to create particulates and can be moved over the long distances before being dumped again to water or soil. Atmospheric N deposition has amplified over current decades and varies from 5–80 kg ha^{-1} yr^{-1} with a worldwide average of around 17 kg ha^{-1} yr^{-1} have been noticed. Land application of the dilute waste wasters generally has lower NH_3 emissions as compared to the more solid waste because of a reduction in NH_4^+ content and the penetration of liquid waste into the soil, decreasing atmospheric contact. Therefore, dilute wastes usually have lower NH_3 emissions, but possibly greater NO_3^- and N_2O emissions.

Application of wastewaters and animal slurries to soils encourages DE nitrification via the supply of available C and N for the microbial respiration and by encouraging anaerobic conditions in the soils via partial sealing of the soil pores and consumption of oxygen through the C oxidation. Storage of dung triggers the buildup of impulsive fatty acids which are degradable shapes of C. Microbial denitrification related to land-spreading of the organic wastes can be a vital source of effective greenhouse gas, N_2O. Emissions of N_2O from the slurry spreading are primarily linked to the application approach, and the temperature of soil combined with the moisture of soil at the time of application. Methods for decreasing N_2O emissions related with wastewaters comprise restricting the hydraulic loading to confirm soils remain aerobic; modifying application timings to when soils aren't anaerobic; altering application approach/rate; inclusion of the nitrification inhibitors to slow the NO_3^- formation rate; manipulation of C/N ratio; storage or digestion to decrease labile C content and presence of materials having high cation interchange capacity e.g., zeolite. A representation of soil N alterations is given in Figure 1.3.

There have been many reports of water contamination taking place after the land-spreading of the wastewaters to soils. Richards et al. (2004) stated nitrate leaching losses varying from 95–323 kg N ha^{-1} when the wastewaters were applied over the range to free-draining soils. Houlbrouke et al. (2004) stated between 2 and 20% of N and P made practical in the agricultural wastewaters filtered through the soils and concentrations leaking were above ecological parameters for the good water quality.

Frequent application of the wastewaters to the soil can trigger an upsurge in organic fractions of P, K, N, and organic carbon because of changes in the soil organic matter. In New Zealand, Barkle et al. (2000). Stated substantial increases in soil complete N and organic C. At the low temperatures, growing soil C content because of the dirty water application can trigger to greater N immobilization because of the variations in soil C/N ratio (Ghani et al., 2005). Increasing the status of soil nutrients above the agronomic optimal has been exhibited to increase the threat of nutrient loss to the water (Sharpley and Tunney, 2000). Other properties of soil can be impacted by land applications like increasing soil pH, variations in soil hydraulic conductivity because of plugging, clogging, and macropore collapse. Repeatedly the actual consequence of land-spreading on the physical properties of soil is hard to quantify because of variability in the physical properties of soil, short-term scrutiny and experimental methods within an experience of seasonal discrepancy in properties (MAFF, 2000; Hawke and Summers, 2006).

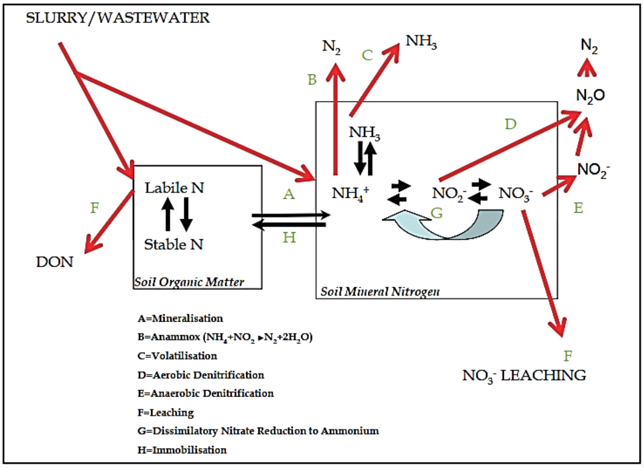


Figure 1.3: Soil N transformations of wastewater/slurry derived nitrogen (N) inputs.

Source: https://www.intechopen.com/books/waste-water-evaluation-and-management/agricultural-dairy-wastewaters.

1.9. NOVEL REMEDIATION METHODS CURRENTLY BEING RESEARCHED

Fenton et al. (2008) studied agricultural wastewaters remediation and control techniques appropriate for Ireland. Several options like utilization of chemical amendments, subsurface carbon positioning, and wetlands were some options anticipated for further research.

1.9.1. Amendments to Dairy Dirty Water and Slurry

Dairy dirty water (DDW) is the bio-product of farming. The usual technique for disposal of the product is land-spreading (Healy et al., 2007). This can upsurge the concentration of P on the surface of the soil and the pollution associated with natural run-off during the rain events. Not numerous researches have been done regarding this subject.

Because of the properties of DDW, the prospective for leaching must also be considered. Usually, P leaching isn't well-thought-out to be an important issue in the groundwater because it isn't very mobile in sediments or soils, and should thus be retained in soil zone. However, in enormously susceptible areas, where the subsoil and soil are shallow and where phosphorus enters groundwater in substantial quantities, groundwater might act as an extra nutrient enrichment path for receptors like lakes, wetlands, and rivers (EPA, 2008). Phosphorus leaching might take place in sandy soils (Carlyle et al., 1998).

In the past, the main objective of chemical adjustment of dung was to decrease NH_3 losses from dung as this augmented N accessibility from plants. In recent years, environmental anxieties have shifted this emphasis to amendments, which lessen P loss from manure and soils. In Ireland, the emphasis of a recent study has been to discover amendments which decrease the solubility of phosphorus in the dairy cattle slurry particularly. The utilization of such amendments should be practical and price effective for the farmers. The effect of decreasing P solubility on decreasing consequent P fertilizer replacement value of material must also be considered. Alum has been used widely to treat poultry mess in the United States for over 30 years with very great success to decrease NH_3 in the poultry houses and lessen soluble P in poultry mess (Moore and Edwards, 2007). The authors also discovered that alum addition to the poultry litter decreased P loss, ammonia volatilization, and had an insignificant effect on metal discharge from amended soil. Work involving alterations of dairy cattle slurries and swine for the management of P have been restricted to the laboratory batch studies with very little focus on feasibility or cost of treatments (Dao, 1999; Dou et al., 2003; Kalbasi and Karthikeyan, 2004; Smith et al., 2001; Moore et al., 1998).

Aluminum chloride has been suggested as the most appropriate amendment for governing P solubility in cattle slurry and swine (Smith et al., 2001). In a development study, Dou et al. (2003) discovered that the technical grade alum added at around 0.1 kg/kg and 0.25 kg/kg decreased

Water Extractable phosphorus in swine and dairy slurry by 99% and 80%, respectively. Dao (1999) altered farmyard dung with calcium carbonate, fly ash, and alum in a development experiment and stated WEP reductions in altered manure as compared to a control of 21, 60, and 85%. Penn et al. (2009) inspected the retention and absorption mechanisms of various P absorbing materials (PSMs) comprising acid mine drainage treatment residuals, fly ash, water treatment residuals, bauxite mining remaining and FGD in the lab experiments and discovered the extent of absorption of phosphorus to be influenced by the buffer capacity of manure, solution pH, and ionic strength of the amendments. These amendments are quite striking as they are free. Though they are more adaptable than commercial coagulants and chemicals used by the other workers and more research is needed before there could be used in practice. Internationally, P absorbing alterations have been used to control phosphorus losses after dung application. P absorbing alterations can be added directly to manure before the land application (Moore et al., 1998), spread on the ground before dung application (McFarland et al., 2003), or integrated into the topsoil (Novak and Watts, 2005).

1.9.2. Permeable Reactive Barriers and Reactive Media for Improved Denitrification

Inexpensive, in situ treatment systems, known as PRB (permeable reactive barriers), might be used to treat groundwater. In this kind of system, N-rich wastewaters flow through a carbon-rich mixture to decrease nitrate concentrations to suitable levels. Organic C alterations offer inexpensive surface and subsurface treatment substitutes for wastewater treatment. The availability of C is a significant parameter that affects the denitrifying activity in soils. The existence of C offers an energy source, thus improving the prospects for denitrification. Denitrification might be augmented in the soils by the addition of an outside C amendment. This amendment might be natural C like woodchip, corn, vegetable oil, wheat straw, sawdust mulch, or some other materials like treated newspaper or the unprocessed cotton (Volokita, 1996). A permeable reactive barrier or de-nitrification wall is the only one of numerous denitrifying bioreactor kinds, i.e., denitrification beds, stream bed bioreactor, up-flow bioreactors, or denitrification layers. The restrictions of a de-nitrification wall are that they need site particular analyses of the hydraulic gradient, the extent and depth of the nitrate plume/s, elimination of nitrate are limited to the up-gradient contamination sources and within upper two meters of groundwater. Problems might ascend if the DE nitrification wall has lower saturated hydraulic conductivity as compared to the surrounding subsoil. If this takes place, nitrate plumes incline to flow around the Denitrification and not through it. Though, in circumstances where nitrate contamination takes place below 2 meters, the diameter of the trench might be widened.

1.9.3. Vertical Flow Systems

Different filter media kinds have been inspected in PRBs. Gilbert et al. (2008). Reviewed 7 types of materials (softwood, hardwood, mulch, willow, coniferous, leaves, and compost) to choose an appropriate natural organic substrate to use in a PBR. Consequent to the batch test, the material used in laboratory-scale research was softwood. The columns were around 0.09 meters in diameter and 0.9 meters long and expected an influent concentration of around 50 mg NO_3-N dm^{-3} loaded from the column base at 2 HLRs: 0.3 cm^3/min and 1.1 cm^3/min. At lower HLR, eliminations of more than 96% were measured, while eliminations of 66% were measured for higher HLR. The influence of residence times was studied by Claus and Kutzner (1985), who reviewed N elimination in an up-flow crammed bed reactor, with the lava stones as provision for the microbial growth. Utilizing nitrate solution of dissimilar concentrations (1.8; 3.0; 4.3; 6.1 g NO^3 L^{-1}) and five diverse residence times (5; 3.3; 2.5; 2.0; 1.7 h), 95% DE nitrification was measured at longest residence time.

Other kinds of filter media like shredded newspaper have been examined. Volokita et al. (1996) treated water in the 0.55 meter-high × 0.1 meter-diameter laboratory columns using shredded newspaper. Complete nitrate elimination of inlet solution was accomplished at an ambient temperature of around 32°C. Sawdust has quite a high DE nitrification rates because of its large surface area but is disposed to clogging. Bedessem et al. (2005) used a mixture of native soil and sawdust in a 4.6 meter-long, 7.6 centimeter-diameter laboratory column to treat synthetic wastewater. The total nitrogen elimination was 31% in the control column and 67% in columns with the organic layer. Saliling et al. (2007) assessed wheat straw and woodchips using an up-flow bioreactor. The concentration of influent was around 200 mg NO_3-N L^{-1} and 99% elimination was obtained. Vrtovšek and Roš (2006) inspected the efficiency of a 1-meter long × 0.12-meter diameter fixed-bed biofilm reactor, including a mixture of powdered activated carbon and PVC plastic as packing material. The reactor was vaccinated with municipal wastewaters before an operation. Influent water with a concentration of around 45 mg NO_3-N L^{-1} and the sodium acetate was loaded from the base of the column. Different rates of loading were applied to a column, with the drinking water quality being accomplished at NLR (nitrogen loading rates) of lower than 1.9 g NO_3-N m^{-2} d^{-1}. Phillips and Love (2002) examined a denitrifying bio-filter to eliminate nitrate from circulating again aquaculture system waters using an up-flow immobile film column and two fermentation columns.

Two nitrate concentrations were loaded at the HLR of 3.0 m hr^{-1}. The column was crammed with the polystyrene media with a particular surface area of around 1000 m^2 m^{-3} and was planted with triggered sludge before the operation. Commercial fish food was used as a source of fermentation. Nitrate elimination of greater than 99% was achieved. Rocca et al. (2007) used a coupling HAD (heterotrophic-autotrophic denitrification) processes reinforced by cotton and ZVI (zero-valent iron) to measure the reduction of nitrate. Two-column sets full of cotton and 300 g or 150 g of ZVI were used in this experiment.

A laboratory sulfur-based RBS was assessed by Moon et al. (2008), and was capable to alter 60 mg N L^{-1} in di-nitrogen in the existence of phosphate. The rate of DE nitrification was higher than 95%. Cameron and Schipper (2010) associated nitrate elimination, hydraulic, and nutrient leakage characteristics of 9 different carbon (C) substrates. Mean nitrate elimination rates for the era 10 to 23 months were around 19.8 and 15 g N m^{-3} d^{-1} for maize cobs, 7.8 and 10.5 g N $m^{-3}d^{-1}$ for green waste, 5.8 and 7.8 g N m^{-3} d^{-1} for wheat straw, 3.0 and 4.9 g N m^{-3} d^{-1} for softwood, and 3.3 and 4.4 g N m^{-3} d^{-1} for hardwood for 14 and 23.5 carbon treatments, respectively.

1.9.4. Horizontal Flow Systems

These systems have also been used in studies. Healy et al. (2006) inspected the utilization of several wood materials as the source of carbon in the laboratory horizontal flow filters to denitrify nitrate from the synthetic wastewater. The filter materials used were: sawdust, sand and sawdust, sand and sawdust, and sand and medium-chip woodchips. 2 influent NO_3-N concentrations, 60 mg L^{-1}, and 200 mg L^{-1}, loaded at 19.4 to 2.9 mg NO_3-N kg^1 mixture d^{-1}, were used. The horizontal flow filter with the sand/woodchip mixture, loaded at the 2.9 mg NO_3-N kg^{-1} d^{-1}, executed best, yielding a 97% reduction in NO_3-N at the steady-state conditions. Utilizing a sand tank comprising a denitrifying zone in the center, Hunter (2001) measured the 39% nitrate elimination of the primary concentration of around 20 mg NO_3-N L^{-1} at the flow rate of 1112 L/week.

1.9.5. Wetlands

DDW can have a substantial hostile consequence on the environment. In recent years, the utilization of CWs (constructed wetlands) for the treatment of DDW, along with municipal and domestic wastewaters, has been attaining in popularity. This is because of their comparatively low capital expenses and maintenance requirements.

1.9.6. Wetland Types

There are two types of CW: FWS CWs (free water surface constructed wetlands) and the subsurface CWs. In FWS CWs, the wastewater flows in a shallow layer of water over the soil substrate. Subsurface CWs might be SSHF CWs (subsurface horizontal flow CWs) or SSVF CWs (subsurface vertical flow CWs). In SSHF CWs, the wastewater flows horizontally over the substrate. In SSVF CWs, the wastewater is dosed subsurface horizontal flow CWs spasmodically onto the surface of gravel filters and sand and slowly drains over the filter media before gathering in the drain at base. CWs might be planted with a mixture of submerged, growing, and in the situation of FWS CWs, the floating vegetation. However, the capability of vegetation to seizure nutrients, mainly in the cool temperate climate, is restricted (Healy et al., 2007).

1.9.7. Design Guidelines for the Dairy Dirty Water Treatment

American guidelines for design loading of subsurface horizontal flow CWs treating agricultural wastewater (NRCS, 1991) suggest an aerial OLR of around 7.3 g five-day BOD_5 (biochemical oxygen demand) $m^{-2}d^{-1}$; similar rates are used in wetland design for the cool temperature climates (Cooper et al., 1996; Dunne et al., 2005ab). New Zealand guidelines for disposal of the DDW (Tanner and Kloosterman, 1997) suggested that an FWS CW must only succeed 2 waste stabilization ponds before arriving at the wetland with OLR not surpassing 3 g BOD_5 m^{-2} d^{-1}. Normally, FWS CWs are used for the treatment of the DDW as problems like blockage of filter media-usually related to the process of SSHF CWs-don't arise.

1.9.8. Treatment Efficacy

Outcomes from CWs have been variable. Table 1.4 presents the performance of free water surface CWs in the treatment of the DDW in several countries. In the study of unplanted and planted subsurface horizontal flow CWs, where the unplanted subsurface horizontal flow CWs acted as the experimental control, Tanner (1995ab) discovered that under five-day $CBOD_5$ (carbonaceous biochemical oxygen demand) OLRs varying from 0.9–3.4 g $CBOD_5$ m^{-2} d^{-1} (unplanted) and 0.9–4.1 g $CBOD_5$ m^{-2} d^{-1} in case of planted, maximum $CBOD_5$ eliminations of 85% and 92%, respectively, were measured. Ammonification was pronounced with growing HRT, and total nitrogen elimination varied between 48% and 80% for planted CWs. Similar OLRs were used in research on a three-cell incorporated FWS CW in Co. Wexford, Ireland (Dunne et al., 2005ab) where under OLRs ranging from 2.7–3.5 g BOD_5 m^{-2} d^{-1}, the good organic elimination was measured, but nitrification wasn't complete during winter.

Cronk et al. (1994) also discovered that under concentrated retention times BOD_5 and suspended solids concentrations weren't lessened to acceptable levels after the treatment in a one-cell FWS CW and that no substantial lessening of TKN (total Kjeldahl nitrogen) occurred. In research on the dairy farm in the Drointon in the United Kingdom (Cooper et al., 1996), and SSHF CW was used to treat influent with the average BOD_5 concentration of around 1192 mg L^{-1}. The system primarily used only the wetland and executed poorly under the early OLR of 26 g BOD_5 m^{-2} d^{-1}. However, when 2 SSVF CWs and the lagoon were deployed in front of SSHF CW, then the system had an OLR of nearly 4 g BOD_5 m^{-2} d^{-1} and also had good organic and suspended solids elimination rates, but had restricted nitrification because of large fluctuations in inlet wastewater strength. Even under considerably reduced OLRs, FWS, and SSHF CWs have under-performed.

Table 1.4: Average Effluent and Influent Concentration, Loading Rates, and Elimination Effectiveness of Wetlands Treating DDW (Dairy Dirty Water)

Parameter	**Wetland**	**Loading**	**Influent**	**Effluent**	**Removal**
	Type	**Rate**	± SD	± SD	**Efficiency**
BOD					
Ireland	FWS		998±1034	16±5	98
USA	FWS	~12	242	246	–2
	FWS	~60	7130	2730	62
	FWS	18	2680	611	77
	FWS	NP	1914	59	97
Italy	FWS	~1.9	451	28	94
Australia	FWS	5.6	220	90	59

N. Zealand	FWS	~1	337	11	92
	FWS	~4.1	113	27	76
COD					
Ireland	FWS		1718±2008	162±83	91
SS					
USA	FWS	NP	5540	990	82
	FWS	NP	1645	65	96
	FWS	NP	911	641	30
	FWS	9	1284	130	90
Ireland	FWS		535±434	34±31	94
N. Zealand	FWS	~8.5	150	33	78
	FWS	~1.9	142	34	76
Tot-N					
N. Zealand	FWS	2.7	~38	20	48
	FWS	0.6	~38	10	75
USA	FWS	0.7	103	74	28
	FWS	NP	170	13	92
NH_4-N					
Israel	FWS	NP	51	44	14
USA	FWS	0.05	8	52	0
	FWS	NP	72	32	56
Ireland	FWS		48±25	6±5	88
N. Zealand	FWS	NP	33	22	34
	FWS	NP	38	11	71
NO_3-N					
USA	FWS	NP	5.5	10	0
	FWS	2×10^{-3}	0.3	0.1	67
Tot-P					
N. Zealand	FWS	0.8	~11	6.9	37
	FWS	0.2	~11	2.9	74
USA	FWS	NP	53	2.2	96
	FWS	0.2	26	14	46
PO_4-P					
Ireland	FWS		15±7	3±2	80

Avg±SD; FWS → free water surface built wetland.

NP →not published.

Current agricultural practice in the state of Ireland is controlled by European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2009 (S.I. No. 101 of 2009), which then places a charge on the specific farmer and public authority to observe the conditions decided within the Nitrates Directive (EEC, 1991(a)) and the other water quality directives to confirm good wastewater management practices. On account of this, CWs are becoming quite popular for the treatment of the DDW. Healy and O' Flynn (*pers. comm.*) assessed the performance of 7 CWs treating DDW in Ireland. They discovered that the average eliminations of COD (chemical oxygen demand) from DDW were around 91%. However, the average effluent concentrations were around 162 mg L^{-1}, which was quite higher than the MAC (maximum allowable concentration). The performance of CWs in the lessening of NH_4N and the ortho-phosphorus was also highly adaptable (Fingelton and Cushion, 1999).

REFERENCES

1. ADAS, (1985). *Dirty Water Disposal on the Farm* (Vol. 1, pp. 1–30). Ministry of Agriculture, Fisheries, and Food, London.
2. ADAS, IGER, & SSRC, (1994). *Low Rate Irrigation of Dilute Farm Wastes* (Vol. 262, pp. 1–40). Report for the national rivers authority, R, and D. National Rivers Authority, Bristol.
3. Ayers, R. S., & Westcot, D. W., (1985). FAO irrigation and drainage paper. *Water Quality for Agriculture, 29*, 156.
4. Aislabie, J. M., Fraser, R. H., Smith, J., & McLeod, M., (2001). Leaching of bacterial indicators through four New Zealand soils. *Australian Journal of Soil Research, 39,* 1397–1406.
5. Anon, (2005). *European Communities (Good Agricultural Practice for Protection of Waters) Regulations (2005)* (Vol. 1, pp. 40–47). SI 788 of (2005). Department of Environment, Heritage, and Local Government, the Stationary Office, Dublin.
6. Anon, (2006). *European Communities (Good Agricultural Practice for Protection of Waters) Regulations (2006)* (Vol. 1, pp. 40–49). SI 378 of (2006). Department of Environment, Heritage, and Local Government, the Stationary Office, Dublin.
7. Anon, (2009). *European Communities (Good Agricultural Practice for Protection of Waters) Regulations (2009)* (Vol. 1, pp. 44–50). SI 101 of (2009). Department of Environment, Heritage, and Local Government, the Stationary Office, Dublin.
8. Anon, (2010). *European Communities (Good Agricultural Practice for Protection of Waters) Regulations (2010)* (Vol. 1, pp. 50–53). SI 610 of (2010). Department of Environment, Heritage, and Local Government, the Stationary Office, Dublin.
9. Bachand, P. A. M., & Horne, A. J., (2000). Denitrification in constructed wetland free-water surface wetlands, II. Effects of vegetation and temperature. *Ecological Engineering, 14*, 17–32.
10. Baudart, J., Grabulos, J., Barusseau, J. P., & Lebaron, P., (2000). Salmonella spp. and fecal coli form loads in coastal waters from a point vs. nonpoint source of pollution, *Journal of Environmental Quality, 29,* 241–250.
11. Bedessem, M. E., Edgar, T. V., & Roll, R., (2005). Nitrogen removal in laboratory model leach fields with organic-rich layers. *Journal of Environmental Quality, 34*(3), 936–942.

12. Bolan, N., & Swain, D., (2004). Issues and innovations in land application of farm wastes. New Zealand *Journal of Agricultural Research, 47*, 387–388.

13. Brennan, F. P., O'Flaherty, V., Kramers, G., Grant, J., & Richards, K. G., (2010). Long-term persistence and leaching of *Escherichia coli* in temperate maritime soils. *Applied and Environmental Microbiology, 76*(5), 1449–1455.

14. Brennan, R. B., Fenton, O., & Healy, M. G., (2010a). Chemical amendment of dairy cattle slurry for control of phosphorus in runoff from grasslands. A05 symposium on emerging technologies to remove phosphorus. *ASA-CSA-SSSA International Meetings* (Vol. 1, pp. 1–30), Long Beach, CA. 31st October-4th November 2010.

15. Brennan, R. B., Fenton, O., & Healy, M. G., (2010b). Evaluation of chemical amendments to control soluble phosphorus losses from dairy cattle slurry. In: Turtola, E., Ekholm, P., & Chardon, W., (eds.), *MTT Science 10. Novel Methods for Reducing Agricultural Nutrient Loading and Eutrophication, Meeting of COST 869* (Vol. 869, pp. 1–18). Jokioinen, Finland.

16. Brennan, R. B., Fenton, O., Rodgers, M., & Healy, M. G., (2010c). The addition of chemical amendments to dairy cattle slurry for the control of phosphorus in runoff from grasslands. *BSAS/WPSA/Agricultural Research Forum Conference* (Vol. 1, pp. 1–40). Queen's University, Belfast.

17. Cameron, S. G., & Schipper, L. A., (2010). Nitrate removal and hydraulic performance of organic carbon for use in denitrification beds. *Ecological Engineering, 36*(11), 1588–1595.

18. Carlyle, J. C., Bligh, M. W., & Nambiar, E. S., (1998). Woody residue management to reduce nitrogen and phosphorus leaching from sandy soil after clear-felling *Pinus radiata* plantations. Canadian *Journal of Forest Research, 28*(8), 1222–1232.

19. Claus, G., & Kutzner, H. J., (1985). Autotrophic denitrification by Thiobacillus denitrificans in a packed bed reactor. *Applied Microbiology and Biotechnology, 22*(4), 289–296.

20. Collins, R., McLoed, M., Donnison, A., Close, M., Hanly, J., Horne, D., Ross, C., DaviesColley, R., Bagshaw, C., & Mattews, L., (2007). Best management practices to mitigate fecal contamination by livestock of New Zealand waters. *New Zealand Journal of Agricultural Research, 50*, 267–278.

21. Cooper, P., Job, G. D., Green, M. B., & Shutes, R. B. E., (1996). *Reed Beds and Constructed Wetlands for Wastewater Treatment* (Vol. 1, 178–184). WRC, Swindon, UK.
22. Craggs, R. J., Sukias, J. P., & Davies-Colley, R. J., (2004). Advanced pond system for dairy-farm effluent treatment. *New Zealand Journal of Agricultural Research, 47*, 449–460.
23. Cronk, J. K., Kodmur, V., & Shirmohammadi, A., (1994). An evaluation of wetlands for the treatment of dairy effluent results from the first year of operations. *Presented at the International Winter Meeting of the American Society of Agricultural Engineers* (pp. 11–19). Pap. No. 94–2600, ASAE, St. Joseph, MI, USA.
24. CSO, (2006). *Livestock Survey* (Vol. 1, pp. 1–20).
25. Culleton, N., Liebhardt, W. C., Murphy, W. E., Cullen, J., & Cuddity, A., (2000). *Thirty Years of Phosphorus Fertilizer on Irish Pastures, Animal-Soil-Water Relationships* (Vol. 1, pp. 1–40). Teagasc, Wexford.
26. DAFF, (1996). *Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrates, 1*, 1–30.
27. DAFF, (2003). *Compendium of Irish Agricultural Statistics, Department of Agriculture and Food* (Vol.1, pp. 1–33), Wexford.
28. Dao, T. H., (1999). Co-amendments to modify phosphorus extractibility and nitrogen/phosphorus ration in feedlot manure and composted manure. *Journal of Environmental Quality, 28*, 1114–1121.
29. Demanet, R., Aguilera, M., & Mora, M., (1999). Effect of applying prunes on the sole-plant system. Arricola Frontier, *No 5*, 87–94.
30. Donnison, A., & Ross, C., (2003). Campylobacter and farm dairy effluent irrigation. *New Zealand Journal of Experimental Agriculture, 46*, 255–262.
31. Dou, Z., Zhang, G. Y., Stout, W. L., Toth, J. D., & Ferguson, J. D., (2003). Efficacy of Alum and Coal Combustion By-Products in Stabilizing Manure Phosphorus. *Journal of Environmental Quality, 32*, 1490–1497.
32. Dunne, E. J., Culleton, N., O'Donovan, G., Harrington, R., & Olsen, A. E., (2005a). An integrated constructed wetland to treat contaminants and nutrients from dairy farmyard dirty water. *Ecological Engineering, 24*, 221–234.
33. Dunne, E. J., Culleton, N., O'Donovan, G., Harrington, R., & Daly, K., (2005b). Phosphorus retention and sorption by constructed wetland

soils in south-east Ireland. *Water Research, 39*(18), 4355–4362.

34. EC, (1991). *Directive 91/676/EEC Concerning the Protection of Waters Against Pollution Caused by Nitrates from Agricultural Sources*, *375*, 1–8.
35. EC, (1998). Council Directive (98/83/EC) of 3rd November 1988 on the quality of water intended for human consumption. *Official Journal of the European Communities,* (Vol. L220/32, pp. 1–30). Brussels, Belgium.
36. EC, (2000). *Water Framework Directive [(2000)/60/EC] Establishing a Framework for Community Action in the Field of Water Policy* (Vol. 1, pp. 1–30).
37. EEC, (1975). Council Directive (75/440/EEC) of 16th of June 1975 concerning the quality required of surface water intended for the abstraction of drinking water in the Member States. *Official Journal of the European Communities, 1*, 1–20).
38. EEC, (1980). Council Directive (80/68/EEC) of 17th December 1979 on the protection of groundwater against pollution caused by certain dangerous substances. *Official Journal of the European Communities, L20*, 43–48.
39. EEC, (1991a). Council Directive (91/271/EEC) of 12th December 1991 concerning the protection of waters caused by nitrates from agriculture sources. *Official Journal of the European Communities, 1*, 1–33).
40. EEC, (1991b). Council directive (91/271/EEC) of 21st May 1991 concerning urban wastewater treatment. *Official Journal of the European Communities, 1*, 1–29).
41. EPA, (2004). *Biological Survey of River Quality-Results of the (2003) Investigations EPA* (Vol. 1, pp. 1–20), Wexford.
42. EPA, (2008). *Water Quality in Ireland, 2004–2006, 1*, 1–30.
43. Fenton, O., Healy, M., & Schulte, R. P. O., (2008). A review of remediation and control systems for the treatment of agricultural wastewater in Ireland to satisfy the requirements, of the water framework directive. *Biology and Environment Proceedings of the Royal Irish Academy 108*(B), 69–79.
44. Fenton, O., Healy, M. G., Brennan, R. B., Serrenho, A. J., Lalor, S. T., O Huallacháin, D., & Richards, K. G., (2011). *Agricultural Dairy Wastewaters* (Vol. 1, pp. 447–470). InTech.
45. Fenton, O., Healy, M. G., & Rodgers, M., (2009a). Use of ochre from

an abandoned metal mine in the South East of Ireland for phosphorus sequestration from dairy dirty water. *Journal of Environmental Quality, 38*(3), 1120–1125.

46. Fenton, O., Richards, K. R., Haria, A., Johnson, P., Horan, B., Murphy, P., Premrov, A., Coxon, C., Humphreys, J., & Necpalova, M., (2009). Travel time from source to receptor in four contrasting case studies in Ireland to illustrate the effect of lag time on achieving the goals of the WFD. Tearmann, *The Irish Journal of Agrienvironmental Research, 7*, 129–142.
47. Fingelton, W. A., & Cushion, M., (1999). Irish agriculture in figures 1998, Dublin. *Teagasc, 1*, 11–29.
48. Food Safety Authority of Ireland, (2008). *Food Safety Implications of Land-Spreading Agricultural, Municipal, and Industrial Organic Materials on Agricultural Land Used for Food Production in Ireland* (Vol. 1, pp. 1–20), FSAI.
49. Geary, P. M., & Moore, J. A., (1999). Suitability of a treatment wetland for dairy wastewaters. *Water Science and Technology, 40*(3), 179–185.
50. Ghani, A., Dester, M., Sarathchandra, U., & Waller, J., (2005). Effects of dairy factory effluent application on nutrient transformation in soil. *New Zealand Journal of Agricultural Research, 48*, 241–253.
51. Gibert, O., (2008). Selection of organic substrates as potential reactive materials for use in a denitrification permeable reactive barrier (PRB). *Bioresource Technology, 99*(16), 7587–7596.
52. Hawke, R. M., & Summers, S. A., (2006). Effects of land application of farm dairy effluent on soil properties, a literature review. *New Zealand Journal of Agricultural Research, 49*, 307–320.
53. Healy, M., Rodgers, M., & Mulqueen, J., (2007). Treatment of dairy wastewater using constructed wetlands and intermittent sand filters. *Bioresource Technology, 98*(12), 2268–2281.
54. Healy, M. G., Newell, J., & Rodgers, M., (2007). Harvesting effects on biomass and nutrient retention in a free-water surface constructed wetland in western Ireland. *Biology and Environment, Proceedings of the Royal Irish Academy, 107B*, 139–145.
55. Healy, M. G., Rodgers, M., & Mulqueen, J., (2006). Denitrification of a nitrate-rich synthetic wastewater using various wood-based media materials. *Journal of Environmental Science and Health. Part A, Toxic/Hazardous Substances and Environmental Engineering, 41*(5), 779–

788.

56. Hiscock, K., Lovett, A., Saich, A., Dockerty, T., Johnson, P., Sandhu, C., Sunnenberg, G., Appleton, K., Harris, B., & Greaves, J., (2007). Modeling land-use scenarios to reduce groundwater nitrate pollution, the European Water4All project. *Quarterly Journal of Engineering Geology and Hydrogeology, 40*(4), 417–434.
57. Houlbrooke, D. J., Horne, D. J., Hedley, M. J., Hanly, J. A. D. R., & Snow, V. O., (2004). A review of literature on the land treatment of farm dairy effluent in New Zealand and its impacts on water quality. *New Zealand Journal of Agricultural Research, 47*, 499–511.
58. Houlbrooke, D. J., Horne, D. J., Hedley, M. J., Hanly, J. A., Scotter, D. R., & Snow, V. O., (2004). Minimising surface water pollution from farm dairy effluent application to mole pipe drained soils. An evaluation of the deferred irrigation system for sustainable land treatment in the Manawatu. *New Zealand Journal of Agricultural Research, 47*, 405–415.
59. Humphreys, J., Casey, I. A., Darmody, P., Connell, K. O., Fenton, O., & Watson, C. J., (2008). Quantities of mineral N in soil and concentrations of nitrate-N in groundwater in four grassland-based systems of dairy production on a clay-loam soil in a moist temperate climate. *Grass and Forage Science, 63*(4), 481–494.
60. Hunter, W. J., (2001). Use of vegetable oil in a pilot-scale denitrifying barrier. *Journal of Contaminant Hydrology, 53*(1–2), 119–131.
61. Jamieson, R. C., Gordon, R. J., Sharples, K. E., Stratton, G. W., & Madani, A., (2002). Movement and persistence of fecal bacteria in agricultural soils and subsurface drainage water, a review. *Canadian Biosystems Engineering, 44*, 1.1–1.9.
62. Kalbasi, M., & Karthikeyan, K. G., (2004). Phosphorus dynamics in soils receiving chemically treated dairy manure. *Journal of Environmental Quality, 33*, 2296–2305.
63. Karpiscak, M. M., Freitas, R. J., Gerba, C. P., Sanchez, L. R., & Shamir, E., (1999). Management of dairy waste in the Sonoran Desert using constructed wetland technology. *Water Science and Technology, 40*(3), 57–65.
64. Kay, D., Aitken, M., Crowther, M. J., Dickson, I., Edwards, A. C., Francis, C., Hopkins, M., Jeffrey, W., Kay, C., McDonald, A. T., McDonald, D., Stapleton, C. M., Watkins, J., Wilkinson, J., & Wyer, M.

D., (2007). Reducing fluxes of fecal indicator compliance parameters to bathing waters from diffuse agricultural sources, The Brighouse Bay study, Scotland. *Environmental Pollution, 147,* 138–149.

65. Kebede-Westhead, E., Pizarro, C., & Mulbry, W. W., (2004). Treatment of dairy manure effluent using freshwater algae, elemental composition of algal biomass at different manure loading rates. *Journal of Agricultural Food Chemistry, 52*(24), 7293–7296.
66. Knight, R. L., Payne, Jr. V. W. E., Borer, R. E., Clarke, Jr. R. A., & Pries, J. H., (2000). Constructed wetlands for livestock management. *Ecological Engineering, 15*, 41–55.
67. Lalor, S., (2010). *Efficient and Reliable Utilization of Nutrients in Animal Manures* (Vol. 1, pp. 1–35). Technical report, Teagasc.
68. Lalor, S. T. J., Schröder, J. J., Lantinga, E. A., Oenema, O., Kirwan, L., & Schulte, R. P. O., (2010). Nitrogen fertilizer replacement value of cattle slurry in grassland as affected by method and timing of application. *Journal of Environmental Quality, 1*, 1–30.
69. Lu, S. Y., Wu, F. C., Lu, Y. F., Xiang, C. S., Zhang, P. Y., & Jin, C. X., (2009). Phosphorus removal from agricultural runoff by constructed wetland. *Ecological Engineering, 35*, 402–409.
70. Lucey, J., (2009). Water quality in Ireland-2007–2008. *Key Indicators of the Aquatic Environment* (Vol. 1, pp. 1–44). EPA, Wexford.
71. MAFF, (2000). *Fertilizer Recommendations Handbook for Agriculture and Horticulture Crops (RB209),* (7th edn., Vol. 1, pp. 1–20, 175). Ministry of Agriculture, Fisheries, and Food (MAFF). The Stationary Office, London, U.K.
72. Mantovi, P., Marmiroli, M., Maestri, E., Tagliavini, S., Piccinini, S., & Marmiroli, N., (2003). Application of a horizontal subsurface flow constructed wetland on treatment of dairy parlor wastewater. *Bioresource Technology, 88*, 85–94.
73. Martínez-Suller, L., Provolo, G., Brennan, D., Howlin, T., Carton, O. T., Lalor, S. T. J., & Richards, K. G., (2010a). A note on the estimation of nutrient value of cattle slurry using easily determined physical and chemical parameters. *Irish Journal of Agricultural and Food Research, 49,* 93–97.
74. Martínez-Suller, L., Provolo, G., Carton, O. T., Brennan, D., Kirwan, L., & Richards., K. G., (2010b). The composition of dirty water on dairy farms in Ireland. *Irish Journal of Agricultural and Food Research, 49*,

67–80.

75. McFarland, A. M. S., Hauck, L. M., & Kruzic, A. P., (2003). Phosphorus reductions in runoff and soils from land-applied dairy effluent using chemical amendments, an observation. *The Texas Journal of Agriculture and Natural Resource, 1*, 47–59.
76. McLeod, M., Aislabie, J. M., Ryburn, J., McGill, A., & Taylor, M. D., (2003). Microbial and chemical tracer movement through two Southland soils, New Zealand. *Australian Journal of Soil Research 41*, 1163–1169.
77. Minogue, D., Murphy, P., French, P., Coughlan, F., & Bolger, T., (2010). *Characterization of Soiled Water on Irish Dairy Farms* (Vol. 1, pp. 1–30). BSAS & Agricultural Research Forum, Belfast, N. Ireland.
78. Moon, H. S., (2008). A long-term performance test on an autotrophic denitrification column for application as a permeable reactive barrier. *Chemosphere, 73*(5), 723–728.
79. Moore, P. A., & Edwards, D. R., (2007). Long-term effects of poultry litter, alum-treated litter, and ammonium nitrate on phosphorus availability in soils. *Journal of Environmental Quality, 36*, 163–174.
80. Moore, P. A., Daniel, T. C., Gilmour, J. T., Shreve, B. R., Edwards, D. R., & Wood, B. H., (1998). Decreasing metal runoff from poultry litter with aluminum sulphate. *Journal of Environmental Quality, 27*, 92–99.
81. Mulbry, W. W., & Wilkie, A. C., (2001). Growth of benthic freshwater algae on dairy manures. *Journal of Applied Phycology, 13,* 301–306.
82. Newman, J. M., Clausen, J. C., & Neafsey, J. A., (2000). Seasonal performance of a wetland constructed to process dairy milk house wastewater in Connecticut. *Ecological Engineering, 14*, 181–198.
83. Novak, J. M., & Watts, D. W., (2005). An alum-based water treatment residual can reduce extractable phosphorus concentrations in three phosphorus-enriched coastal plain soils. *Journal of Environmental Quality, 34*, 1820–1827.
84. NRCS, (1991). Technical requirements of agricultural wastewater treatment. *National Bulletin No. 210–1–17,* (pp. 1–50). National Resource Conservation Service, United States Department of Agriculture, Washington, DC, USA.
85. Pell, A. N., (1997). Manure and microbes, public, and animal health problem? *Journal of Dairy Science, 80*, 2673–2681.
86. Penn, C. J., Bryant, R. B., Callahan, M. A., & McGrath, J. M.,

(2009). Use of industrial byproducts to sorb and retain phosphorus. *Communications in Soil Science and Plant Analysis, 1,* 1–30.

87. Phillips, J. B., & Love, N. G., (2002). Biological denitrification using up flow biofiltration in recirculating aquaculture systems, Pilot-scale experience, and implications for full-scale. In: *Proceedings of the 2nd International Conference on Recirculating Aquaculture, 2*(1), 1–40.
88. Pizarro, C., Kebede-Westhead, E., & Mulbry, W., (2002). Nitrogen and phosphorus removal rates using small algal turfs grown with dairy manure. *Journal of Applied Phycology, 14*(6), 469–473.
89. Provolo, G., & Martínez-Suller, L., (2007). In situ determination of slurry nutrient content by electrical conductivity. *Bioresource Technology, 98*, 3235–3242.
90. Ran, N., Agami, M., & Oron, G., (2004). A pilot study of constructed wetlands using duckweed (Lemma gibba L.) for treatment of domestic primary effluent in Israel. *Water Research, 38*, 2241–2248.
91. Regan, J. T., Rodgers, M., Healy, M. G., Kirwan, L., & Fenton, O., (2010). Determining phosphorus and sediment release rates from five Irish tillage soils. *Journal of Environmental Quality, 39*(1), 185–192.
92. Richards, K., Ryan, M., & Coxon, C. E., (2004). Dirty water: A valuable source of nitrogen on dairy farms, 12th Nitrogen Workshop, Reading, U.K. In: Hatch, D. J., Chadwick, D. R., Jarvis, S. C., & Roker, J. A., (eds.), *Controlling Nitrogen Flows and Losses* (Vol. 1, pp. 439–440). Wageningen Academic Publishers, The Netherlands.
93. Rocca, C. D., Belgiorno, V., & Meriç, S., (2007). Heterotrophic/autotrophic denitrification (HAD) of drinking water, prospective use for permeable reactive barrier. *Desalination, 210*(1–3), 194–204.
94. Ryan, D., (2005). *A Slurry Spreader to Meet Farming Needs and Environmental Concerns* (Vol. 1, pp.1–30). Teagasc, Wexford.
95. Salazar, F., Carlos-Dumont, J., Chadwick, D., Salana, R., & Santana, M., (2007). Characterization of dairy slurry in southern Chile farms. *Agricultura Technica (Chile), 67*(2), 155–162
96. Saliling, W. J. B., Westerman, P. W., & Losordo, T. M., (2007). Wood chips and wheat straw as alternative biofilter media for denitrification reactors treating aquaculture and other wastewaters with high nitrate concentrations. *Aquacultural Engineering, 37*(3), 222–233.
97. Sapkota, A. R., Curriero, F. C., Gibson, K. E., & Schwab, K. J., (2007). Antibiotic-resistant enterococci and fecal indicators in surface water

and groundwater impacted by a concentrated swine feeding operation. *Environmental Health Perspectives, 115*, 1040–1045.

98. Schaafsma, J. A., Baldwin, A. H., & Streb, C. A., (2000). An evaluation of a constructed wetland to treat wastewater from a dairy farm in Maryland, USA. *Ecological Engineering, 14*, 199–206.
99. Schröder, J. J., Jansen, A. G., & Hilhorst, G. J., (2005). Long-term nitrogen fertilizer value of cattle slurry. *Soil Use and Management, 21*, 196–204.
100. Schulte, R., Melland, A., Richards, K., Fenton, O., & Jordan, P., (2010). Modeling soil phosphorus decline; expectations of water framework directive policies in Ireland. *Environmental Science and Policy, 13*, 472–484.
101. Scotford, I. M., Cumby, T. R., Han, L., & Richards, P. A., (1998a). Development of a prototype nutrient sensing system for livestock slurries. *Journal of Agricultural Engineering Research, 69*, 217–228.
102. Scotford, I. M., Cumby, T. R., White, R. P., Carton, O., Lorenz, F., Hatterman, U., & Provolo, G., (1998b). Estimation of the nutrient value of agricultural slurries by measurement of physical and chemical properties. *Journal of Agricultural Engineering Research, 71*, 291–305.
103. Serrenho, A., Fenton, O., Lanigan, G., & Healy, M. G., (2010). Pollution swapping in four laboratory carbon rich denitrification systems. In: Raghuram N., Bijay-Singh, Pathak, H., Ahmad A., Jain V., & Pal, M., (eds.), *Proceedings of the 5th International Nitrogen Conference "Reactive Nitrogen Management for Sustainable Development-Science, Technology, and Policy"* (Vol. 5, pp. 266–272). Ashok Hotel, New Delhi, India.
104. Serrenho, A. J., Fenton, O., Rodgers, M., & Healy, M. G., (2010). Laboratory study of a denitrification system using a permeable reactive barrier. *BSAS/WPSA/Agricultural Research Forum Conference* (Vol. 1, pp. 12–14). Queen's University, Belfast.
105. Skerrett, H. E., & Holland, C. V., (2000). The occurrence of Cryptosporidium in environmental waters in the greater Dublin area. *Water Research, 34*, 3755–3760.
106. Smith, D. R., Moore, P. A., Jr., Haggard, B. E., Maxwell, C. V., Daniel, T. C., Van, D. K., & Davis, M. E., (2004). Effect of aluminum chloride and dietary phytase on relative ammonia losses from swine manure.

Journal of Animal Science, 82, 605–611.

107. Smith, K., & Chambers, B., (1993). Utilizing the nitrogen content of organic manures on farms problems and practical solutions. *Soil Use and Management, 9,* 105–112.
108. Sommer, S. G., Schjoerring, J. K., & Denmead, O. T., (2004). Ammonia emission from mineral fertilizers and fertilized crops. *Advances in Agronomy, 82*, 557–622
109. Stark, C. H., & Richards, K. G., (2008). The continuing challenge of agricultural nitrogen loss to the environment in the context of global change and advancing research. *Dynamic Soil, Dynamic Plant, 2*, 1–12.
110. Tanner, C. C., & Kloosterman, V. C., (1997). Guidelines for constructed wetland treatment of farm dairy wastewaters in New Zealand. *NIWA Science and Technology Series No. 48* (pp. 1–30). Hamilton, New Zealand.
111. Tanner, C. C., Clayton, J. S., & Upsdell, M. P., (1995a). Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands-I, Removal of oxygen demand, suspended solids and fecal coliforms. *Water Research, 29*, 17–26.
112. Tanner, C. C., Clayton, J. S., & Upsdell, M. P., (1995b). Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands-II, Removal of nitrogen and phosphorus. *Water Research, 29*, 27–34.
113. Topp, E., Scott, A., Lapen, D. R., Lyautey, E., & Duriez, P., (2009). Livestock waste treatment systems for reducing environmental exposure to hazardous enteric pathogens, some considerations. *Bioresource Technology, 100*, 5395–5398.
114. Tunney, H., Coulter, B., Daly, K., Kurz, I., Coxon, C., Jeffery, D., Mills, P., Kiely, G., & Morgan, G., (2000). *Quantification of Phosphorus Loss to Water Due to Soil P Desorption. Final Report* (Vol. 1, pp.1–30). Environmental Monitoring R&D Report Series No.6. EPA, Wexford.
115. Tyrrel, S. F., (1999). The microbiological quality of water used for irrigation. *Irrigation News, 27*, pp. 39–42.
116. Vanotti, M. B., Szogi, A. A., Hunt, P. G., Millner, P. D., & Humenik, F. J., (2007). Development of environmentally superior treatment system to replace anaerobic sine lagoons in the USA. *Bioresource Technology, 98*, 3184–3194.
117. Venglovsky, J., Sasakova, N., & Placha, I., (2009). Pathogens and

antibiotic residues in animal manures and hygienic and ecological risks related to subsequent land application. *Bioresource Technology, 100,* 5386–5391

118. Villar, M. C., Diaz-Fierros, F., Cabaneiro, A., Leiros, M., Gil Sostres, F., Carballas, M., & Carballas, T., (1979). Fast methods for the characterization of beef purin. In: "*Use of Residual Organic Materials as Fertilizers in Galician Agriculture" Project N.3365–79* (Vol. 1, pp. 1–100).
119. Volokita, M., Belkin, S., Abeliovich, A., & Soares, M. I. M., (1996). Biological denitrification of drinking water using newspaper. *Water Research, 30*, 965–971.
120. Vrtovšek, J., & Roš, M., (2006). Denitrification of groundwater in the biofilm reactor with a specific biomass support material. *Acta Chim. Slov., 53*, 396–400.
121. Wang, L., Li, Y., Chen, P., Min, M., Chen, Y., Zhu, J., & Ruan, R. R., (2010). Anaerobic digested dairy manure as a nutrient supplement for cultivation of oil-rich green microalgae *Chlorella sp. Bioresource Technology, 101*(8), 2623–2628.
122. Ward, A. J., Hobbs, P. J., Holliman, P. J., & Jones, D. L., (2008). Optimization of the anaerobic digestion of agricultural resources. *Bioresource Technology, 99*, 7928–7940.

2

Applications of Wastewater Resource

CONTENTS

2.1. INTRODUCTION

Water has become a limiting factor in several semiarid 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 and 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).

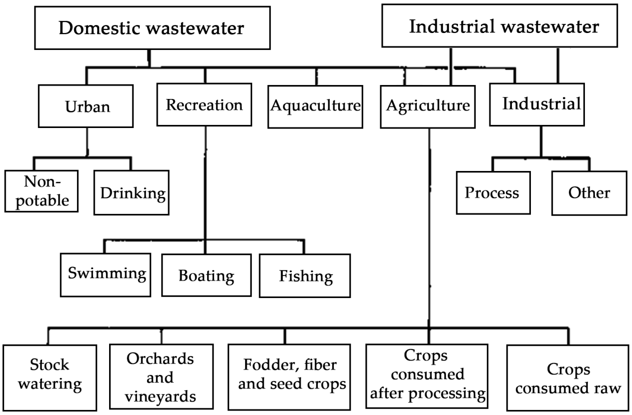


Figure 2.1: Types of wastewater use (WHO, 1989).

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 and 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 and World Health Organization, 1995). This rest of this chapter focuses 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 subsections (Trang et al., 2007a, b).

2.2.2. Urban

Reclaimed wastewater, in urban areas, has been used primarily for nonpotable 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; and
6. Urinal flushing and toilet in industrial and commercial buildings.

The drawbacks of urban nonpotable 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 and 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 and 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 and Rehman, 2011):

1. For power stations evaporative cooling water;
2. Boiler-feed water;
3. Development of water; and
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 and Van Lier, 2005; Rehman and 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 and 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 and 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 and 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 sociocultural reception of the practice; and
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) (Table 2.1).

Table 2.1: Increases in Crop Yields (Tons ha^{-1} a^{-1}) Arising from Wastewater Irrigation in Nagpur, India

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]

[1] years of harvest (to calculate average yield).

Source: Shende (1985).

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 overuse 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; and
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 semiarid 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 and 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 and 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 and 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; and
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; and
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 (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 defecated pathogens, containing high pathogen concentrations in the digestive tract and incursion of fish muscle by bacteria and the intraperitoneal 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, fasciolopsiasis 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 intraperitoneal fluid of the fish there should be high standards of hygiene during fish gutting and handling.

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

Table 2.2: Recommended Microbiological Guidelines for Wastewater Use in Agriculture

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 coli form 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

[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.*

Source: WHO (1989).

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, sodium adsorption ratio (SAR), 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 anemia diseases; 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, cooperatives, 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 interagency 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, a National Fisheries Board (NFB) might be responsible for the aquacultural use of wastewater, and excreta and a National Irrigation Board (NIB) 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 interagency committees have these basic responsibilities (Ormerod and 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 interagency 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, the National Water Commission (CNA) is established in charge of the administration, planning, and control of all wastewater use schemes at the national level, and is attached to the Ministry of Water and Agriculture Resources, controls the water resources of the country. The 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. There is also a strong contribution by the private sector in the Mesquital Valley, dealing with the management of small irrigation units combined into cooperative systems (Fam and 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 and Leung, 2003):

1. No agriculture and rain-fed agriculture (irrigation) at all;
2. From alternative source irrigation with water without fertilizer application; and
3. From alternative source irrigation with water with fertilizer application.

In a wastewater irrigation project, the following costs must be considered (Papadopoulos, 1990):

i Wastewater treatment costs, comprising site and land preparation, equipment, and materials, system design, civil engineering works.

ii Irrigation costs comprise of conveyance and distribution, storage water handling.

iii 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.

iv 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 and 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 and 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 and 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, Tables 2.3 and 2.4).

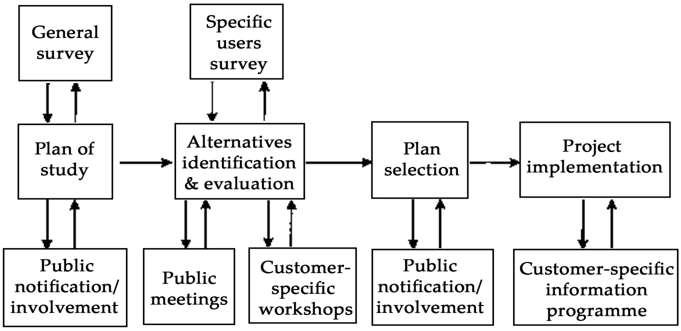


Figure 2.2: A flow chart illustrating a public participation program (After Crook).

Table 2.3: Removal of Excreted Bacteria and Helminths by Various Wastewater Treatment Systems

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

[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.

Source: Mara and Cairncross (1989).

Table 2.4: Reported Effluent Quality from Stabilization Ponds with a Retention Time of 25 days

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

[1] Fecal coliforms per 100 ml.

Source: Bartone and Arlosoroff (1987).

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) (Table 2.5).

Table 2.5: Performance of Five Wastewater Stabilization Ponds (Mean Temperature 26°C)

Sample	**BOD5 (mg l^{-1})**	**Fecal Coliforms**	**Retention Time (Days)**	**Intestinal Nematode Eggs/Liter**	**Suspended Solids (mg l^{-1})**
Facultative pond	45	3.2×10^5	5.5	1	74
Anaerobic pond	63	2.9×10^6	6.8	29	56
Raw wastewater	240	4.6×10^7		804	305
Effluent from					
Maturation pond No. 1	25	2.4×10^4	5.5	0	61
Maturation pond No. 2	19	450	5.5	0	43
Maturation pond No. 3	17	30	5.8	0	45

Source: Mara et al. (1983); Mara and 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 and Elmaci, 2007):

1 High capability to absorb hydraulic and organic loads;

2. No need for energy requirements;

3. Lower maintenance, operation, and construction costs; and
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 min 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).

Table 2.6: Evaluation of Common Irrigation Methods about the Use of Treated Wastewater

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

Source: 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 and Kröpfelová, 2008).

2.4.1.5. Tertiary Treatment

To improve the physicochemical 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 pretreatment 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).

2.4.1.6. Sludge Treatment

The extra sludge produced by biological treatment plants is valued as a source of plant nutrients along with a soil conditioner. It can also be used to fertilize aquaculture ponds or in agriculture. Nevertheless, biological treatment procedures focus on inorganic and organic impurities along with pathogens in the extra sludge. Helminth eggs can remain viable and last for periods of nearly one year given the availability of moisture and nutrients. Raw sludge can be applied to agricultural land in channels and covered with a layer of the earth if suitable care is being taken during the handling process. This should be completed before the start of a planting season and care should be taken that no tuberous plants like potatoes or beets are planted sideways the channels (Braga et al., 2005).

To make sludge's safe for use in aquaculture or agriculture the following treatment methods can be used:

1. Storage at ambient temperature in hot climates from 6–12 months.
2. Mesophilic (around 35°C) anaerobic digestion, which removes only 30–40% of *Ascaris* but removes eggs 90–95% of total parasite eggs, (Gunnerson and Stuckey, 1986).
3. For about 13 days, thermophilic (around 55°C) anaerobic digestion guarantees total inactivation of all pathogens. Constant reactors can let pathogens evade the elimination process and thus the digestion process should be done under batch circumstances (Strauss, 1985).
4. With local solid waste or some other organic bulking agent forced-aeration co-composting of sludge-like wood chips, for 30 days at 55–60°C after that maturation for 2–4 months will produce a constant, pathogen-free compost at ambient temperature, (Obeng and Wright, 1987).

2.4.2. Crop Selection

According to the WHO guidelines for the irrigation of specific crops wastewater of great microbiological quality is needed, mostly crops eaten uncooked (see Table 4.2). Since lower quality, waters will distress consumers and other unprotected groups like crop handlers and field workers an inferior quality is acceptable however for irrigation of specific types of crop and equivalent levels of exposure to the groups at risk. For instance, crops which are generally cooked like potatoes, or industrial crops like sisal and cotton, do not need high-quality wastewater for irrigation (Hussain and Al-Saati, 1999).

According to the group of persons expected to be exposed and the degree to which health protection measures are compulsory crops can be divided into two extensive categories:

1. **Category A:** Protection was compulsory for the general public, agricultural workers, and the consumers. This category contains crops expected to be eaten uncooked, public parks, sports fields spray-irrigated fruits, and lawns.
2. **Category B:** Protection compulsory for agricultural workers only, since there would be no microbiological health dangers linked with the consumption of the crops if they were watered with wastewater (since crops in this category are not eaten raw, or they are treated before they reach the consumer so there is no risk to consumers). This category contains fodder crops, industrial crops, trees, cereal crops, pastures, and food crops for canning. If they are not eaten raw (peas and potatoes), or if they raise well above the ground (green beans, tomatoes, and chilies), some vegetable crops may be counted in this category. In these scenarios, it is important to make sure that the crop is not polluted by falling to the ground or by sprinkler irrigation, and that contamination of kitchen utensils by these crops, before cooking, does not give rise to health dangers (Keraita et al., 2010; George et al., 2018).

The practice of crop restriction concludes that crops that are permitted to be watered with wastewater are restricted to those certain under category B. Although this category protects consumers further, protective measures are required for farmworkers (see below).

Although it looks straightforward and simple, in reality, it is very tough to implement and to apply crop restriction policies. If a crop restriction policy is fully implemented and enforced it is only effective for health protection. It needs the capacity to control and to monitor compliance with the conventional crop restriction regulations and a durable institutional framework. Agriculturalists should be advised of the necessity and importance of the restriction policy and be aided in developing a stable mix of crops that makes full use of the existing partially treated waste-water. The possibility of following is more where (Mohammad and Ayadi, 2004):

1. There is satisfactory demand for the crops permitted under the policy and they get a suitable price;
2. A public body under strong central management regulates the allocation of wastewater;.
3. A law-abiding society occurs or the restriction policy is strongly imposed; and
4. In favor of crops in category A, there is little market pressure.

In aquaculture schemes, crop restriction does not give health protection, because macrophytes and fish grown in excreta-fertilized or wastewater ponds are, in several places, consumed uncooked. In many parts of the world a promising and alternative method, already practiced, is to produce duckweed (*Lemna* sp.) in wastewater-fed ponds. The duckweed is then gathered and dried up and nourished to high-value fish grownup in freshwater ponds. To yield fishmeal for animal feed (or for fish food) the similar method can be used by rising the fish to be used for the production of fishmeal in wastewater ponds (Segarra et al., 1996).

2.4.3. Irrigation Techniques

To irrigate crops the different approaches used by farmers can be grouped under five headings (Kandiah, 1994b):

1. **`Sprinkler Irrigation:** Water in this category is applied in the form of a spray and influences the soil in the same way as rain (e.g., solid, and portable set sprinklers, center-pivot systems, spray guns, and traveling sprinklers).
2. **Localized Irrigation:** Around each plant or group of plants water is applied so that only the root zone becomes wet (e.g., micro-sprinklers, bubblers, and drip irrigation).
3. **Furrow Irrigation:** Between ridges, water is applied (e.g., graded, and level furrows, corrugations, and contour furrows). The water reaches the ridge (where the plant roots are concentrated) by capillary action.

4. **Flood Irrigation:** Over the entire field water is applied to penetrate the soil (e.g., borders, contour flooding, wild flooding, and basins).
5. **Sub-Surface Irrigation:** Beneath the root zone water is applied in such a way that it wets the root zone by the capillary rise (e.g., buried pipes, and subsurface canals).

The type of irrigation method selected depends on the soil, climate, water supply conditions, the capability of the farmer to manage the system, the cost of irrigation approaches and the crops to be grown (Phocaides, 2000; Jiang et al., 2012).

For decreasing the negative effects of wastewater, there is significant scope, use in irrigation over the selection of suitable irrigation methods. The choice of method is ruled by the succeeding technical factors:

1. Crops type that's need to be irrigated;
2. The wetting of aerial parts, fruits, and foliage;
3. The distribution of contaminants, salts, and water in the soil;
4. Ease through which high soil-water potential can be upheld;
5. Application's efficiency; and
6. The potential to pollute the environment and farmworkers.

Table 2.7 evaluates these factors with four broadly applied irrigation methods, namely border, drip irrigation, sprinkler, and furrow.

A border (as well as any flood irrigation or a basin) system includes complete exposure of the soil surface by treated wastewater which is not generally an effective method of irrigation. This system pollutes vegetable crops growing near the ground and root crops and, too much than any other method, exposures field workers to the pathogen amount of wastewater. Therefore, for both water and health protection, border irrigation with wastewater is not reasonable (Brito et al., 2009; Howard et al., 2011).

Table 2.7: Different Levels of Tools for Public Participation in the Decision to Reuse Wastewater

Purpose	**Tools**
Interaction dialogue	Interviews, special task forces, Workshops, advisory boards, seminars, study group discussions, informal contacts

Education and information	Speeches and presentations, conferences, newspaper articles, information depositories, exhibits, field trips, letters, films, brochures, and newsletters, reports, school programs, radio, and TV programs
Review and reaction	Public hearings, public meetings, briefings, advertised "hotlines" for telephone inquiries, question, and answer columns, surveys, and questionnaires

Source: Crook et al. (1992).

Since plants are grown on ridges, furrow irrigation can decrease crop contamination and does not wet the whole soil surface. Whole health safety cannot be guaranteed and the danger of contamination of farmworkers is possibly medium to high, relying on the amount of automation of the process. The risk to irrigation workers is least if the treated wastewater flows through pipes and sent into individual furrows by way of gated pipes. To evade surface ponding of standing wastewater, which may encourage the growth of disease vectors, smoothing of the land should be carried out carefully and suitable land gradients should be provided.

Spray, or sprinkler, irrigation approaches are generally more effective in water use because better uniformity of application can be attained. Such overhead irrigation methods, however, can contaminate farmworkers, fruit trees, and ground crops. Furthermore, pathogens confined in the wastewater aerosol can be transported downwind and make a health hazard to neighboring residents. Usually, automated or mechanized systems have quite high investment costs and low labor costs related to the manually operated sprinkler schemes. To avoid excessive heat loss and to attain uniformity of wetting rough leveling of the land is essential for sprinkler systems. The quality of the water affects sprinkler systems more than the surface irrigation systems, mainly because of blockage of the orifices in the sprinkler heads but then also because of dregs accumulation in distribution systems, valves, and pipes. If the wastewater is brackish and comprises excessive poisonous elements, there is also the potential for phytotoxicity and leaf burn. Secondary treatment systems that fulfill the WHO microbiological guidelines have normally been found to yield sewage suitable for distribution through sprinklers if the wastewater is not too brackish. Further protective measures like treatment with sand filters or micro-strainers and expansion of the nozzle orifice to diameters not < 5 mm, are often implemented.

Localized irrigation, mainly when the soil surface is protected with other mulch or plastic sheeting, uses sewage more proficiently. It gives higher crop yields and surely gives the greatest extent of health protection to consumers and farmworkers. Though, drip and trickle irrigation systems are costly and need great quality of treated wastewater to avoid blockage of the orifices through which water is come out into the soil. A quite new technique known as "bubbler irrigation," which was established for restricted irrigation of tree crops, evades the requirements for small orifices. This system needs, thus, needs careful setting for effective application but less treatment of the wastewater.

The main advantages of drip irrigation when related to other systems are:

1. Improved crop growth and yield attained by optimizing the air regimes, nutrients, and water in the root zone.
2. High irrigation productivity since there is no conveyance losses, wind drift or covering interception, and nominal drainage loss.
3. Nominal contact between wastewater and farmworkers.
4. Low energy supplies since the trickle system need a water pressure of just 100–300 kPa (1–3 bar).
5. Low labor supplies since the drip system can be easily computerized, even to let fertilization and combined irrigation.

Along with the high capital costs of drip irrigation systems, another restrictive factor in their practice is that they are generally suitable for the irrigation of crops that are planted in rows. Repositioning of subsurface systems can be extortionately expensive.

When wastewater irrigation is achieved special field managing practices that may be essential, include alternating treated wastewater through other sources of supply, a combination of waste-water with other water supplies, and pre-planting irrigation.

The extend of wastewater to be used relies on the rate of evapotranspiration (ET_c) through the plant surface, which is determined by climatic factors and can thus be appraised with reasonable precision, by using meteorological data. In FAO, a general review of this subject is presented (1984).

2.4.4. Integrated Measures for Health Protection

To decision-makers and planners, wastewater treatment seems like a more upfront and "visible" measure for health safety, second just to crop restriction. However, both actions are comparatively difficult to implement completely. The first is restricted by operational and costs problems and the second by the deficiency of suitable markets for allowable crops or by institutional and legal constraints. The application of single, inaccessible actions will not, however, offer full safety to the groups at risk and may involve high costs of maintenance and execution. For example, crop restriction, if functional alone gives protection to customers of crops but not to field workers (Drechsel et al., 2002).

To evaluate the several measures in a combined fashion intended for the optimization of a health safety scheme, a comprehensive model has been proposed (Mara and Cairncross, 1989; WHO, 1989). This model was considered to aid in decision making, by revealing the variety of options for the crop consuming public and protecting agricultural workers, and by permitting flexibility in responses to diverse situations. Each condition can be measured separately and the most suitable option selected after taking into account technical factors, cultural, and economic (Rauch et al., 1998).

In Figure 2.3, the graphical conception of the model is shown. It was presumed that pathogens stream to the center of the circle going from the five concentric rings representative excreta or wastewater, irrigated field or consumers of crops, field workers, and wastewater-fed fishpond. A barricade beyond which pathogens should not go if the health of the groups at danger is to be protected can be signified by the thick black ring. The level of contamination of crop, field, or wastewater, or the level of danger to workers or consumers, is specified by the concentration of the shading. White areas in the three outer bands show no significant or zero levels of contamination and they show an assumed absence of risk to human health, thus representing that the approach will guide to the safe use of wastewater in the inner rings. Both consumers and field workers will be at the maximum risk of contamination if no protective actions are taken. Presumptuous that a policy of crop constraint is imposed (regime A in Figure 2.3) workers will still be at high risk but consumers will be safe. Regime B assumes that the application of wastewater is completed from localized or subsurface irrigation, thus evading crop contamination and, subsequently, keeping both consumers and workers almost free of contamination.

If the single protective measure is taken that is human exposure control, both consumers and field workers will still be given into the same level of danger since these measures are hardly fully effective in practice. Regime D assumes limited treatment of wastewater from conventional (D-I) or ponding systems (D-II). With an average retention time of 8–10 days, stabilization ponds can eradicate an important amount of helminth eggs, therefore ensuring safety to field workers. But, the decrease of bacteria present is not enough to fulfill WHO guidelines and therefore the danger to consumers remains high. Since common treatment, systems are not effective at helminth elimination there will be some residual risk for both field workers and consumers (Barbagallo et al., 2012).

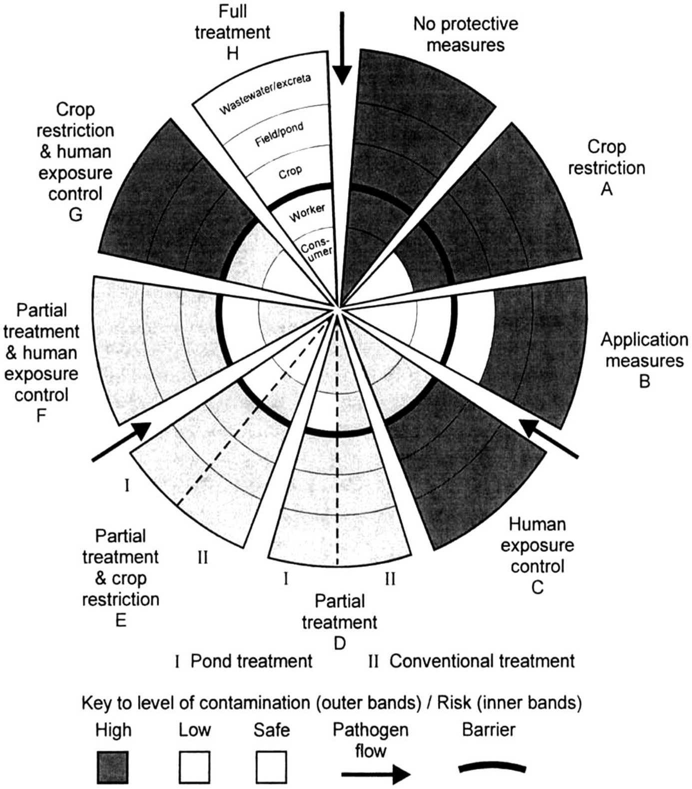


Figure 2.3: A model illustrating the effect of control measures in reducing health risks from wastewater use (After Mara and Cairncross, 1989; WHO, 1989).

Source: https://www.who.int/water_sanitation_health/resourcesquality/wpcc-hap4.pdf.

Examples of the many possible associations of protective actions are the regimes E, F, and G. Regime E assimilates partial wastewater treatment through crop constraint, therefore if a large border of protection to consumers of crops. Full safety of field workers can be attained, however, only if the treatment is complete through well-designed systems of stabilization ponds. Human exposure control is combined in regime F, with limited treatment which may guide to the full protection of workers but some minor level of risk enduring to consumers of the crops. The association of crop restriction through human contact control (regime G) offers thorough protection to customers but some risk remains there to field workers. In conclusion, regime H offers full wastewater treatment permitting for full protection to both consumers and field workers.

The efficacy and feasibility of any blend of protective measures will rely on numerous local factors which must be measured sensibly before the last choice is made. Some factors to be measured are the availability of financial, human, and institutional resources, the present technological level (agronomic and engineering practices), sociocultural features, and the predominant pattern of excreta-related sicknesses (Carr et al., 2004).

REFERENCES

1. Abdel-Shafy, H. I., Hobus, I., & Hegemann, W., (2011). Upgrading of decentralized ponds for municipal wastewater treatment and restricted reuse. *Journal of Water Reuse and Desalination*, *1*(3), 141–151.
2. Adrados, B., Sánchez, O., Arias, C. A., Becares, E., Garrido, L., Mas, J., et al., (2014). Microbial communities from different types of natural wastewater treatment systems: Vertical and horizontal flow constructed wetlands and biofilters. *Water Research*, *55*, 304–312.
3. Al-Sa'ed, R., & Mubarak, S., (2006). Sustainability assessment of onsite sanitation facilities in Ramallah-Albireh district with an emphasis on technical, socio-cultural, and financial aspects. *Management of Environmental Quality: An International Journal*, *17*(2), 140–156.
4. Angelakis, A. N., Bontoux, L., & Lazarova, V., (2003). Challenges and prospectives for water recycling and reuse in EU countries. *Water Science and Technology: Water Supply*, *3*(4), 59–68.
5. Angelakis, A. N., Do Monte, M. M., Bontoux, L., & Asano, T., (1999). The status of wastewater reuse practice in the Mediterranean basin: The need for guidelines. *Water Research*, *33*(10), 2201–2217.
6. Arthur, J. P., (1983). *Notes on the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries. Technical Paper No. 7,* (pp. 1–40). World Bank, Washington, D.C.
7. Austin, G., (2013). Multifunctional wastewater treatment landscapes. *Landscape Journal*, *32*(2), 199–214.
8. Barbagallo, S., Cirelli, G. L., Consoli, S., Licciardello, F., Marzo, A., & Toscano, A., (2012). Analysis of treated wastewater reuse potential for irrigation in Sicily. *Water Science and Technology*, *65*(11), 2024–2033.
9. Bartone, C., Moscoso, J., Nava, H., & Mocetti, N., (1986). Aquaculture with treated wastewater: A status report on studies conducted in Lima, Peru. In: Cointreau, S. J., (ed.), *Applied Research and Technology. Technical Note No. 3*, (pp. 1–33). Integrated Resource Recovery Project. UNDP/World Bank, Washington, D.C.
10. Bartone, C. R., (1991). International perspective on water resources management and wastewater reuse-appropriate technologies. *Water Science and Technology*, *23*(10–12), 2039–2047.
11. Bartone, C., Moscoso, J., & Nava, H., (1990). Reuse of waste stabilization effluents for fish culture: productivity and sanitary quality results. In: Charles, R. O., (ed.), *Environmental Engineering*,

Proceedings of the 1990 (pp. 8–11, 673–680). Specialty Conference, Arlington, Virginia, American Society of Civil Engineers, New York.

12. Bartone, C. R., (1985). Reuse of wastewater at the San Juan de Miraflores stabilization ponds: public health, environmental, and socioeconomic implications. *PAHO Bulletin*, *19*(2), 147–164.
13. Bartone, C. R., (1991). International perspective on water resources management and wastewater use-appropriate technologies. *Wat. Sci. Tech., 23,* 2039–2047.
14. Bartone, C. R., & Arlosoroff, S., (1987). Irrigation reuse of pond effluents in developing countries. *Wat. Sci. Tech., 19*(12), 289–297.
15. Bauer, H., Fuerhacker, M., Zibuschka, F., Schmid, H., & Puxbaum, H., (2002). Bacteria and fungi in aerosols generated by two different types of wastewater treatment plants. *Water Research*, *36*(16), 3965–3970.
16. Bazza, M., (2003). Wastewater recycling and reuse in the Near East Region: Experience and issues. *Water Science and Technology: Water Supply*, *3*(4), 33–50.
17. Becerra-Castro, C., Lopes, A. R., Vaz-Moreira, I., Silva, E. F., Manaia, C. M., & Nunes, O. C., (2015). Wastewater reuse in irrigation: A microbiological perspective on implications in soil fertility and human and environmental health. *Environment International*, *75*, 117–135.
18. Bian, Y., Yan, S., & Xu, H., (2014). Efficiency evaluation for regional urban water use and wastewater decontamination systems in China: A DEA approach. *Resources, Conservation, and Recycling*, *83*, 15–23.
19. Biswas, A. K., (1988). Role of wastewater reuse in water planning and management. In: Biswas, A. K., & Arar, A., (eds.), *Treatment*, and *Reuse of Wastewater* (Vol. 1, pp. 310–315). Butterworth's, London.
20. Braga, O., Smythe, G. A., Schäfer, A. I., & Feitz, A. J., (2005). Fate of steroid estrogens in Australian inland and coastal wastewater treatment plants. *Environmental Science and Technology*, *39*(9), 3351–3358.
21. Brito, P. R., Souza, L. C., de Oliveira, J. C. M., Alves, F. R., De-Deus, G., Lopes, H. P., & Siqueira, Jr. J. F., (2009). Comparison of the effectiveness of three irrigation techniques in reducing intracanal Enterococcus fecal is populations: An *in vitro* study. *Journal of Endodontics*, *35*(10), 1422–1427.
22. Buechler, S., Mekala, G. D., Keraita, B., & Van, V. R., (2006). Wastewater use for urban and peri-urban agriculture. Cities farming for the future, urban agriculture for sustainable cities. In: Veenhuizen,

R. V., (ed.), *RUAF Foundation, IDRC, and IIRR*, *9*, 243–273.

23. Butt, A. S., & Rehman, A., (2011). Isolation of arsenite-oxidizing bacteria from industrial effluents and their potential use in wastewater treatment. *World Journal of Microbiology and Biotechnology*, *27*(10), 2435–2441.
24. Capra, A., & Scicolone, B., (2007). Recycling of poor quality urban wastewater by drip irrigation systems. *Journal of Cleaner Production*, *15*(16), 1529–1534.
25. Carr, R. M., Blumenthal, U. J., & Duncan, M. D., (2004). Guidelines for the safe use of wastewater in agriculture: Revisiting WHO guidelines. *Water Science and Technology*, *50*(2), 31–38.
26. CNA, (1993). *General Information of the Irrigation Districts 03 Tula e 100, Alfajayucan, State Management* (Vol. 1, pp. 1–33), Pachuca, Hidalgo, Mexico. National Water Commission, Mexico City.
27. Cobham, R. O., & Johnson, P. R., (1988). The use of treated effluent for irrigation: A case study from Kuwait. In: Pescod, M. B., & Arar, A., (eds.), *Treatment and Use of Sewage Effluent for Irrigation* (Vol. 1, pp. 289–305). Butterworths, London.
28. Crook, J., Ammermman, D. K., Okun, D. A., & Matthews, R. L., (1992). *Guidelines for Water Reuse* (Vol. 1, pp. 1–34). Camp Dresser & McKee, Inc., Cambridge, Massachusetts.
29. Cross, P., (1985). Existing practices and beliefs in the utilization of human excreta. In: *Health Aspects of Night soil and Sludge Use in Agriculture and Aquaculture.* Part I, IRCWD (Report No. 04/85, pp. 1–44), International reference centre for waste disposal, Duebendorff, Switzerland.
30. Drechsel, P., Blumenthal, U. J., & Keraita, B., (2002). Balancing health and livelihoods. *Adjusting Wastewater Irrigation Guidelines for Resource-Poor Countries Urban Agriculture Magazine*, *8*, 7–9.
31. Edwards, P., (1992). Reuse of human excreta in aquaculture: A technical review. *UNDP and World Bank Water and Sanitation Programme* (Vol. 1, pp. 1–24), World Bank, Washington, D.C.
32. El Gammal, H. A., & Ali, H. M., (2011). Commissioning of abandoned drainage water reuse systems in Egypt: a case study of upgrading the Umoum Project, Nile Delta. *Irrigation and Drainage*, *60*(1), 115–122.
33. Fam, D. M., & Mitchell, C. A., (2013). Sustainable innovation in wastewater management: Lessons for nutrient recovery and reuse.

Local Environment, *18*(7), 769–780.

34. FAO, (1984). Guidelines for predicting crop water requirements. *FAO Irrigation and Drainage* (Paper No. 24, pp. 1–43). Food and Agriculture Organization of the United Nations, Rome.
35. FAO, (1985). Water quality for agriculture. *FAO Irrigation and Drainage* (Vol. 29, No. 1, pp. 1–33), Food, and Agriculture Organization of the United Nations, Rome.
36. Farroq, S., & Ansari, Z. I., (1983). Water reuse in Muslim countries: An Islamic perspective. *Environ. Manag., 7*(2), 119–123.
37. Forero, R. S., (1993). *Institutional, Economic, and Sociocultural Considerations*. WHO/FAO/UNCHS/UNEP Regional Workshop for the Americas on Health, Agriculture, and Environmental Aspects of Wastewater Use. Jiutepec, Morelos, Mexico (Vol. 8–12, pp. 1–100). Instituto Mexicano de Tecnologia de Agua (IMTA), Jiutepec, Mexico.
38.
39. Friedler, E., Lahav, O., Jizhaki, H., & Lahav, T., (2006). Study of urban population attitudes towards various wastewater reuse options: Israel as a case study. *Journal of Environmental Management*, *81*(4), 360–370.
40. George, M. R., Pettygrove, G. S., & Davis, W. B., (2018). Crop selection and management. In: *Irrigation with Reclaimed Municipal Wastewater: A Guidance Manual* (Vol. 1, pp. 1–17). CRC Press.
41. Gianico, A., Bertanza, G., Braguglia, C. M., Canato, M., Laera, G., Heimersson, S., et al., (2015). Upgrading a wastewater treatment plant with thermophilic digestion of thermally pretreated secondary sludge: Techno-economic and environmental assessment. *Journal of Cleaner Production*, *102*, 353–361.
42. Gunnerson, C. G., & Stuckey, D. C., (1986). *Anaerobic Digestion, Principles, and Practices for Biogas System. World Bank* (Vol. 49, pp. 1–34). World Bank, Washington, D.C.
43. Gurel, M., Iskender, G., Ovez, S., Arslan-Alaton, I., Tanik, A., & Orhon, D., (2007). A global overview of treated wastewater guidelines and standards for agricultural reuse. *Fresenius Environmental Bulletin*, *16*(6), 590–595.
44. Gutterres, M., & De, A. P. M., (2013). Wastewater reuse focused on industrial applications. In: *Wastewater Reuse and Management* (Vol. 1, pp. 127–164). Springer, Dordrecht.

45. Hespanhol, I., (1990). Health and technical aspects of the use of wastewater in agriculture and aquaculture. In: Rodrigues, F., (ed.), *Socioeconomic*, and *Environmental Issues in Water Projects-Selected Readings* (Vol. 1, pp. 157–190). Economic Development Institute of the World Bank/World Health Organization Washington, D.C.
46. Hespanhol, I., & Prost, A. M. E., (1994). WHO guidelines and national standards for reuse and water quality. *Water Research*, *28*(1), 119–124.
47. Hidalgo, D., Irusta, R., Martinez, L., Fatta, D., & Papadopoulos, A., (2007). Development of a multifunction software decision support tool for the promotion of the safe reuse of treated urban wastewater. *Desalination*, *215*(1–3), 90–103.
48. Howard, R. K., Kirkpatrick, T. C., Rutledge, R. E., & Yaccino, J. M., (2011). Comparison of debris removal with three different irrigation techniques. *Journal of Endodontics*, *37*(9), 1301–1305.
49. Huibers, F. P., & Van Lier, J. B., (2005). Use of wastewater in agriculture: the water chain approach. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *54*(S1), S3–S9.
50. Hussain, G., & Al-Saati, A. J., (1999). Wastewater quality and its reuse in agriculture in Saudi Arabia. *Desalination*, *123*(2–3), 241–251.
51. Ikramullah, M., (1994). Integrated duckweed-based aquaculture and rural enterprise promotion project. *Paper Presented at the WHO/FAO/UNCHS/UNEP Regional Workshop on Health, Agricultural, and Environmental Aspects of Wastewater and Excreta Use* (pp. 1–33), New Delhi, India.
52. Jiang, L. M., Lak, B., Eijsvogels, L. M., Wesselink, P., & Van, D. S. L. W., (2012). Comparison of the cleaning efficacy of different final irrigation techniques. *Journal of Endodontics*, *38*(6), 838–841.
53. Johansson, P., Pernrup, M., & Rångeby, M., (1996). Low-cost upgrading of an oversized wastewater stabilisation pond system in Mindelo, Cape Verde. *Water Science and Technology*, *33*(7), 99–106.
54. Kandiah, A., (1994a). The use of wastewater in the context of overall water resources planning and policy. *Paper Presented at the WHO/FAO/UNCHS/UNEP Workshop on Health, Agriculture, and Environment Aspects of the Use of Wastewater* (Vol. 1, pp. 1–44). Harare, Zimbabwe, WHO, Geneva.
55. Kandiah, A., (1994b). The use of wastewater in irrigation. *Paper*

Presented at the WHO/FAO/UNCHS/UNEP Workshop on Health, Agriculture, and Environment Aspects of the Use of Wastewater (Vol. 1, pp. 1–55). Harare, Zimbabwe, WHO, Geneva.

56. Kaosol, T., & Sohgrathok, N., (2012). Enhancement of biogas production potential for anaerobic co-digestion of wastewater using decanter cake. *American Journal of Agricultural and Biological Sciences*, *7*(4), 494–502.
57. Keraita, B., Drechsel, P., & Amoah, P., (2003). Influence of urban wastewater on stream water quality and agriculture in and around Kumasi, Ghana. *Environment and Urbanization*, *15*(2), 171–178.
58. Keraita, B., Konradsen, F., & Drechsel, P., (2010). Farm-based measures for reducing microbiological health risks for consumers from informal wastewater-irrigated agriculture. *Wastewater Irrigation*, *189*, 1–30.
59. Keremane, G. B., & McKay, J., (2007). Successful wastewater reuse scheme and sustainable development: a case study in Adelaide. *Water and Environment Journal*, *21*(2), 83–91.
60. Laugeri, L., (1989). *Economic Aspects of Wastewater Reuse* (Vol. 1, pp. 1–24). Unpublished document. World Health Organization, Geneva.
61. Lee, J. W., Kwon, T. O., & Moon, I. S., (2005). Performance of polyamide reverse osmosis membranes for steel wastewater reuse. *Desalination*, *177*(1–3), 69–82.
62. Liu, S., Ying, G. G., Zhao, J. L., Zhou, L. J., Yang, B., Chen, Z. F., & Lai, H. J., (2012). Occurrence and fate of androgens, estrogens, glucocorticoids, and progestagens in two different types of municipal wastewater treatment plants. *Journal of Environmental Monitoring*, *14*(2), 482–491.
63. Lu, W., & Leung, A. Y., (2003). A preliminary study on potential of developing shower/laundry wastewater reclamation and reuse system. *Chemosphere*, *52*(9), 1451–1459.
64. Lyu, S., Chen, W., Zhang, W., Fan, Y., & Jiao, W., (2016). Wastewater reclamation and reuse in China: opportunities and challenges. *Journal of Environmental Sciences*, *39*, 86–96.
65. Mara, D. D., Cairncross, S., & World Health Organization, (1989). *Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture: Measures for Public Health Protection*. *World Health Organization, 1*, 1–30.

66. Mara, D. D., (1976). *Sewage Treatment in Hot Climates* (Vol. 1, pp. 5–44). John Wiley & Sons Chichester.
67. Mara, D. D., & Cairncross, S., (1989). *Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture* (Vol. 1, pp. 11–24). World Health Organization/United Nations Environment Programme, Geneva.
68. Mara, D. D., & Silva, S. A., (1986). Removal of intestinal nematode eggs in tropical waste stabilization ponds. *J. Trap. Med. and Hyg., 89*(2), 71–74.
69. Mara, D. D., Pearson, H. W., & Silva, S. A., (1983). Brazilian stabilization pond research suggests low cost urban applications. *World Wat., 6*(7), 20–24.
70. McNeill, L. S., Almasri, M. N., & Mizyed, N., (2009). A sustainable approach for reusing treated wastewater in agricultural irrigation in the West Bank-Palestine. *Desalination*, *248*(1–3), 315–321.
71. Mizyed, N. R., (2013). Challenges to treated wastewater reuse in arid and semiarid areas. *Environmental Science and Policy*, *25*, 186–195.
72. Mohammad, M. J., & Ayadi, M., (2004). Forage yield and nutrient uptake as influenced by secondary treated wastewater. *Journal of Plant Nutrition*, *27*(2), 351–365.
73. Molina, A., & Melgarejo, J., (2016). Water policy in Spain: Seeking a balance between transfers, desalination, and wastewater reuse. *International Journal of Water Resources Development*, *32*(5), 781–798.
74. Nassar, A., Al-Najar, H., & Al-Dadah, J. Y., (2009). Socio-economic aspects of wastewater reuse in the Gaza strip. *Journal of Environmental Science and Technology*, *2*(4), 170–178.
75. Obeng, L. A., & Wright, F. W., (1987). *The Co-composting of Domestic Solid and Human Wastes* (pp. 1–44). World Bank Technical Paper No. 57, World Bank, Washington, D.C.
76. Ormerod, K. J., & Scott, C. A., (2013). Drinking wastewater: Public trust in potable reuse. *Science, Technology, & Human Values*, *38*(3), 351–373.
77. Ou, W. S., Lin, Y. F., Jing, S. R., & Lin, H. T., (2006). Performance of a constructed wetland-pond system for treatment and reuse of wastewater from campus buildings. *Water Environment Research*, *78*(12), 2369–2376.

78. Ozengin, N., & Elmaci, A., (2007). Performance of Duckweed (*Lemna minor* L.) on different types of wastewater treatment. *Journal of Environmental Biology*, *28*(2), 307–314.

79. Özerol, G., & Günther, D., (2005). The role of socioeconomic indicators for the assessment of wastewater reuse in the Mediterranean region. *Non-Conventional Water Use: WASAMED Project Bari: CIHEAM-IAMB*, 169–178.

80. Papadopoulos, I., (1990). *Wastewater Management for Agricultural Production and Environmental Protection in the Near East: A Manual* (Vol. 1, pp. 1–34). Agricultural Research Institute, Nycosia, Cyprus.

81. Parkinson, J., & Tayler, K., (2003). Decentralized wastewater management in peri-urban areas in low-income countries. *Environment and Urbanization*, *15*(1), 75–90.

82. Phocaides, A., (2000). *Technical Handbook on Pressurized Irrigation Techniques* (Vol. 1, pp. 366–372). FAO, Rome.

83. Qadir, M., Bahri, A., Sato, T., & Al-Karadsheh, E., (2010). Wastewater production, treatment, and irrigation in the Middle East and North Africa. *Irrigation and Drainage Systems*, *24*(1–2), 37–51.

84. Raschid-Sally, L., Carr, R., & Buechler, S., (2005). Managing wastewater agriculture to improve livelihoods and environmental quality in poor countries. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *54*(S1), S11–S22.

85. Rauch, W., Aalderink, H., Krebs, P., Schilling, W., & Vanrolleghe, P., (1998). Requirements for integrated wastewater models—driven by receiving water objectives. *Water Science and Technology*, *38*(11), 97–104.

86. Rehman, A., & Anjum, M. S., (2010). Cadmium uptake by yeast, Candida tropical is, isolated from industrial effluents and its potential use in wastewater clean-up operations. *Water, Air, and Soil Pollution*, *205*(1–4), 149.

87. Rehman, A., Farooq, H., & Hasnain, S., (2008). Biosorption of copper by yeast, Loddermyces elongisporus, isolated from industrial effluents: its potential use in wastewater treatment. *Journal of Basic Microbiology*, *48*(3), 195–201.

88. Sadi, I. A., & Adebitan, E. O., (2014). Wastewater recycling in the hospitality industry. *Academic Journal of Interdisciplinary Studies*,

3(7), 87.

89. Saldías, C., Speelman, S., Van, K. B., & Van, H. G., (2016). Institutional arrangements for the use of treated effluent in irrigation, Western Cape, South Africa. *International Journal of Water Resources Development*, *32*(2), 203–218.
90. Salgot, M., Huertas, E., Weber, S., Dott, W., & Hollender, J., (2006). Wastewater reuse and risk: Definition of key objectives. *Desalination*, *187*(1–3), 29–40.
91. Schwartzbrod, L., & World Health Organization, (1995). *Effect of Human Viruses on Public Health Associated with the Use of Wastewater and Sewage Sludge in Agriculture and Aquaculture* (No. WHO/EOS/95.19, pp. 10–40). Geneva: World Health Organization.
92. Scott, C. A., Faruqui, N. I., & Raschid-Sally, L., (2004). Wastewater use in irrigated agriculture: Management challenges in developing countries. *Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities* (Vol. 1, pp. 1–10) CABI Publishing, Wallingford, UK.
93. Segarra, E., Darwish, M. R., & Ethridge, D. E., (1996). Returns to municipalities from integrating crop production with wastewater disposal. *Resources, Conservation, and Recycling*, *17*(2), 97–107.
94. Shende, G. B., (1985). Status of wastewater treatment and agricultural reuse with special reference to Indian experience and research and development needs. In: Pescod, M. B., & Arar, A., (eds.), *Proceedings of the FAO Regional Seminar on the Treatment and Use of Sewage Effluent for Irrigation* (Vol. 1, pp. 1–44). Nicosia, Cyprus, Butterworths, London.
95. Shuval, H. I., (1991). Health guidelines and standards for wastewater reuse in agriculture: Historical perspectives. *Water Science and Technology*, *23*(10–12), 2073–2080.
96. Shuval, H., Lampert, Y., & Fattal, B., (1997). Development of a risk assessment approach for evaluating wastewater reuse standards for agriculture. *Water Science and Technology*, *35*(11–12), 15–20.
97. Shuval, H. I., Adin, A., Fattal, B., Rawitz, E., & Yekutiel, P., (1986). *Wastewater Irrigation in Developing Countries-Health Effects and Technical Solutions* (pp. 11–55). World Bank Technical Paper No. 51, World Bank, Washington, D.C.
98. Siebe, C., & Cifuentes, E., (1995). Environmental impact of wastewater

irrigation in central Mexico: An overview. *International Journal of Environmental Health Research*, *5*(2), 161–173.

99. Sim, W. J., Lee, J. W., Shin, S. K., Song, K. B., & Oh, J. E., (2011). Assessment of fates of estrogens in wastewater and sludge from various types of wastewater treatment plants. *Chemosphere*, *82*(10), 1448–1453.
100. Strauss, M., (1985). Survival of excreted pathogens in excreta and fecal sludge's. *IRCWD News, 23*, (pp. 4–9). Duebendorff, Switzerland.
101. Trang, D. T., Hien, B. T. T., Mølbak, K., Cam, P. D., & Dalsgaard, A., (2007a). Epidemiology and etiology of diarrheal diseases in adults engaged in wastewater-fed agriculture and aquaculture in Hanoi, Vietnam. *Tropical Medicine and International Health*, *12*, 23–33.
102. Trang, D. T., Mølbak, K., Cam, P. D., & Dalsgaard, A., (2007b). Helminth infections among people using wastewater and human excreta in peri-urban agriculture and aquaculture in Hanoi, Vietnam. *Tropical Medicine and International Health*, *12*, 82–90.
103. United Nations, (1958). Water for industrial use. *Economic and Social Council, Report E/3058ST/ECA/50,* pp. 10–39. United Nations, New York.
104. Van, D. H. W., Hassan, M. U., Ensink, J. H., Feenstra, S., Raschid-Sally, L., Munir, S., et al., (2002). *Urban Wastewater: A Valuable Resource for Agriculture: A Case Study from Haroonabad, Pakistan* (Vol. 63, pp. 1–30). IWMI.
105. Van, D. M. B., Peters, I., & Menge, J., (1994). Namibia case study. In: *Health, Agricultural, and Environmental Aspects of Wastewater and Excreta Use*: *Report of a Joint WHO/FAO/UNEP/UNCHS Regional Workshop* (Vol. 1, pp. 7–41). Harare, Zimbabwe, WHO, Geneva.
106. Van, R. D. J., Biggs, T. W., Smout, I., & Drechsel, P., (2010). Urban growth, wastewater production, and use in irrigated agriculture: A comparative study of Accra, Addis Ababa, and Hyderabad. *Irrigation and Drainage Systems*, *24*(1–2), 53–64.
107. Van, R. D. J., Turral, H., & Wade, B. T., (2005). Sponge city: water balance of mega-city water use and wastewater use in Hyderabad, India. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *54*(S1), S81–S91.
108. Vymazal, J., (2009). The use constructed wetlands with horizontal subsurface flow for various types of wastewater. *Ecological*

Engineering, *35*(1), 1–17.

109. Vymazal, J., & Kröpfelová, L., (2008). Types of constructed wetlands for wastewater treatment. *Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow*, 121–202.

110. Wegelin, et al., (1991). The decade of roughing filters-development of a rural water treatment process for developing countries. *Aqua, 40*(5), 304–316.

111. Wegelin, M., (1986). *Horizontal-Flow Roughing Filtration (HRF): A Design, Construction, and Operation Manual. IRCWD Report No. 06/86,* (pp. 1–33). International Reference Centre for Waste Disposal, Duebendorff, Switzerland.

112. WHO, (1989). Health Guidelines for the Use of wastewater in agriculture and aquaculture. *Technical Report Series No. 778* (pp. 1–100). Report of a Scientific Group Meeting, World Health Organization, Geneva.

113. WHO, (1990). Legal issues in water resource allocation, wastewater use, and water supply management. *Report of a Consultation of the FAO/WHO Working Group on Legal Aspects of Water Supply and Wastewater Management* (Vol. 1, pp. 1–34), Geneva, World Health Organization, Geneva.

3

Quality Guidelines for Agricultural Wastewater

CONTENTS

3.1. INTRODUCTION

The measures of health protection which can be made practical in agricultural utilization of wastewater comprise the following, either individually or in combination (Havelaar et al., 2001; Carr et al., 2004):

1. Wastewater treatment;
2. Control of wastewater application;
3. Crop restriction; and
4. Human exposure control and demotion of hygiene.

In the past, the treatment of wastewater has been broadly adopted as the main control measure in governed effluent utilization schemes, with restriction of the crop being used in a few distinguished cases. A more integrated method to the planning of the wastewater utilization in agriculture will take benefit of the optimum amalgamation of the health safety measures accessible and permit for any plant/soil constraints incoming at an economic system suitable to the local institutional and socio-cultural conditions (Blumenthal et al., 1991, 2000).

A WHO (World Health Organization) Technical Report on “Health Guidelines for Utilization of Wastewater in Aquaculture and Agriculture” discusses the incorporation of the several measures available to accomplish effective health protection. Restrictions of the legal or administrative systems in few countries will make a few of these methods difficult to apply, while a shortage of experienced technical staff in the other countries will normally place doubt upon dependence on the treatment of wastewater as the only governing mechanism (Ensink and Van der Hoek, 2009). To accomplish greater flexibility in utilization of the wastewater application as a measure of health protection, irrigation systems should be developed in order to be capable of providing low-quality wastewater and limitations on irrigation method and crops irrigated should become more common (WHO, 1981, 1984; Angelakis et al., 1999).

3.2. HUMAN EXPOSURE CONTROL

Out of the health protection measures stated above, only the human exposure control isn’t dealt with in greater depth. The aim of this method is to avoid the groups of the population at danger from coming into contact with the pathogens in wastewater or to avert any direct contact with pathogens leading to the disease. Four groups of the population are at danger in agricultural utilization of wastewater (Paltiel et al., 2016; Rousis et al., 2017):

1. Crop handlers;
2. Agricultural workers and their families; and
3. Consumers of meat, crops, and milk-those residing near the areas watered with the wastewater and different approaches of exposure control may be applied for every group.

Control measures intended for protecting crop handlers and agricultural field workers include the provision of shielding clothing, upkeep of the high levels of cleanliness, and immunization against selected infections. Examples of the measures are provided in the WHO Technical Report mentioned above. Risks to users can be decreased through cooking the produce of agriculture before consumption and by adopting high standards of food cleanliness, which must be highlighted in the health education-related with wastewater utilization schemes (Peasey, 2000; Madera et al., 2009). Local residents must be kept informed fully on the utilization of wastewater in agriculture so that the residents and their children can avert these areas. Although there isn't any evidence to recommend that those residing near the wastewater-irrigated areas are at substantial risk, sprinklers must not be used within 100 m of roads or houses (Table 3.1).

Table 3.1: Suggested Guidelines of Microbiological Quality for Wastewater Utilization in Agriculture

Category	**Exposed Group**	**Reuse Condition**	**Fecal Coliforms (Geometric Mean no. per 100 ml[c])**	**Intestinal Nematodes[b] (Arithmetic Mean no. of Eggs per Liters**	**Wastewater Treatment Expected to Achieve the Required Microbiological Quality**
A	Workers and consumers	Irrigation of crops possible to be consumed, uncooked, sports fields, public parks	≤ 1000[d]	≤ 1	A series of stabilization ponds made to accomplish the microbiological quality specified, or equivalent treatment

B	Workers	Irrigation of the cereal crops, fodder crops, industrial crops, pasture, and trees	No standard recommended	≤ 1	Retention in the stabilization ponds for around 8 to 10 days or corresponding helminth and fecal coliform elimination
C	None	Localized irrigation of the crops mentioned in category B if exposure of the workers and the public doesn't occur	Not applicable	Not applicable	Pretreatment as needed by irrigation technology, but not less than the primary sedimentation

Source: WHO (1989).

In particular cases, the local sociocultural, epidemiological, and environmental factors must be taken considered, and the guidelines altered accordingly.

A stricter guideline is suitable for public lawns like hotel lawns, with which the population might come into direct contact.In the situation of fruit trees, irrigation must cease 2 weeks before the fruit is picked and no fruit must be picked from the ground. Sprinkler irrigation must not be used.Special care must be taken in the wastewater utilization schemes to confirm that the agricultural workers or public don't use wastewater for domestic or drinking purposes by chance or for the absence of an alternative. All of the wastewater channels, outlets, and pipes must be marked clearly and if possible painted a distinctive color. Wherever likely, outlet fittings must be designed so as to avoid misuse (Westrell et al., 2004; Jan et al., 2010; Qadir et al., 2010).

3.3. GUIDELINES OF EFFLUENT QUALITY FOR HEALTH PROTECTION

Following various meetings of environmental epidemiologists and specialists, a WHO (World Health Organization) Scientific Group on Health Features of Utilization of the Treated Wastewater for Aquaculture and Agriculture arrived at the guidelines of microbiological quality for wastewater utilization in agriculture. These guidelines were centered on the consensus opinion that the real risk linked with irrigation with the treated wastewater is lower than formerly thought and that previous guidelines and standards for effluent quality like the WHO (1984) suggested standards, were excessively restrictive, chiefly in respect of the bacterial pathogens (Hespanhol and Prost, 1994).

The novel guidelines are stricter as compared to the earlier standards in respect of the requirement to decrease the numbers of helminth eggs in the effluents for Category A and B conditions to the level of not more than 1 per liter. Also inferred by guidelines is the anticipation that the protozoan cysts will be decreased to the same level as the helminth eggs. Even though no bacterial pathogen restriction is imposed for the conditions of Category C where only the farmworkers are the exposed individuals, on the evidence that there is no or little evidence representing a danger to such farmworkers from bacteria, some extent of reduction in the bacterial concentration is suggested for any effluent utilization situation (Bartone and Arlosoroff, 1987; Strauss, 1991).

The WHO Scientific Group took into account the new method to effluent quality will increase public health safety for many people who were being infected in the areas where crops consumed uncooked are being watered in an unregulated and often illegal manner with the raw wastewater. It was sensed that the suggested guidelines if accepted, would accomplish this enhancement and set objectives that are both economically and technologically feasible. However, the necessity to understand the guidelines cautiously and adjust these guidelines in the light of local sociocultural, epidemiological, and environmental factors was pointed out (Shuval, 1991).

The guidelines of effluent quality in Table 3.1 are anticipated as the design objectives for wastewater treatment systems, instead of standards needing routine testing of the effluents. Wastewater treatment processes accomplishing the suggested microbiological quality constantly as an outcome of the intrinsic design aspects, instead of by high standards of functional control, are to be favored. Besides the microbiological quality necessities of treated effluents used in agriculture, attention should also be given to the quality parameters of significance in respect of the groundwater pollution and of crop productivity and soil structure (Charles et al., 2005; Harwood et al., 2005).Even though heavy metals might not be an issue with only domestic sewage effluents, all of these elements are possibly present in the municipal wastewater.

3.4. GUIDELINES OF WATER QUALITY FOR MAXIMUM CROP PRODUCTION

Conventionally, irrigation water is divided into several quality classes to guide the consumer to the potential benefits along with problems related to its utilization and to accomplish optimal crop production. The classifications of water quality are only suggestive guidelines and the application of these guidelines will have to be accustomed to conditions that exist in the field. This is due to the fact that the conditions of water utilization in the irrigation system are very intricate and difficult to forecast. The appropriateness of water for irrigation purposes will depend greatly on the climatic conditions, chemical, and physical properties of the soil, salt acceptance of the crop grown and management practices. Therefore, the classification of the water for irrigation systems will be general in nature and appropriate under average utilization conditions (Choudhary et al., 1996; Kladivko et al., 2004).

Various schemes of arrangement for the irrigation water have been anticipated. Ayers and Westcot (FAO, 1977, 1979, 1985) categorized irrigation water into 3 groups based on, sodicity, toxicity, salinity, and miscellaneous hazards. These general guidelines of water quality classification help to recognize possible crop production problems related to the utilization of traditional water sources. The guidelines are applied equally to appraise wastewaters for the purposes of irrigation in terms of the chemical constituents like dissolved salts, comparative sodium content, and the toxic ions. Various basic suppositions were used to describe the range of values in guidelines and the more comprehensive information on this is described by Ayers and Westcot (FAO, 1985, 1988).

Effect of sodium (Na) ions in the irrigation water in decreasing infiltration rate and the soil permeability is reliant on the sodium (Na) ion concentration comparative to a concentration of magnesium and calcium ions and the complete salt concentration, as displayed in the guidelines. It clearly specifies that, for the given value of SAR, an increase in the entire salt concentration is possible to increase the soil permeability and for the given overall salt concentration, an upsurge in SAR will reduce soil permeability.

This demonstrates the fact that the soil permeability hazards caused by sodium (Na) in irrigation water can't be anticipated individually of the dissolved content of the salt of irrigation water or that of the soil's surface layer (Baker and Laflen, 1983; Singh et al., 1996) (Table 3.2).

Table 3.2: Guidelines for Understanding of Water Quality for the Irrigation Purposes

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	**Slight to Moderate**	**Severe**
Salinity				
TDS	mg/l	< 450	450–2000	> 2000
or				
Ec_w[1]	dS/m	< 0.7	0.7–3.0	> 3.0
Infiltration				
20–40		> 5.0	5.0–2.9	< 2.9
12–20		> 2.9	2.9–1.3	< 1.3
6–12		> 1.9	1.9–0.5	< 0.5
3 −6		> 1.2	1.2–0.3	< 0.3
SAR[2] = 0–3 and EC_w		> 0.7	0.7–0.2	< 0.2
Specific Ion Toxicity				
Sodium (Na)				
Sprinkler irrigation	me/I	< 3	> 3	
Surface irrigation	SAR	< 3	3–9	> 9
Chloride (Cl)				
Sprinkler irrigation	m^3/l	< 3	> 3	
Surface irrigation	me/I	< 4	4–10	> 10

Boron (B)	mg/l	< 0.7	0.7–3.0	> 3.0
Miscellaneous Effects				
Bicarbonate (HCO_3)	me/I	< 1.5	1.5–8.5	> 8.5
Nitrogen (NO_3-N)[3]	mg/l	< 5	5–30	> 30
pH	Normal range 6.5–8			

[1] *EC_w →electrical conductivity in deciSiemens/meter at 25°C.*

[2] *SAR →sodium adsorption ratio.*

[3] *NO_3-N →nitrate-nitrogen stated in terms of the elemental nitrogen.*

Source: FAO (1985).

Municipal wastewater effluents might contain several toxic elements, comprising heavy metals, as under applied conditions wastes from numerous informal and small industrial sites are discharged directly into the public sewer system. The toxic elements are usually existent in small amounts and hence they are known as trace elements. Some of them might be eliminated during the process of treatment but others will continue and could cause phytotoxic problems. Therefore, municipal wastewater effluents must be checked for the trace element toxicity risks, chiefly when the trace element pollution is suspected. Table 3.3 gives phytotoxic beginning levels of some chosen trace elements (Bouwer and Idelovitch, 1987).

Table 3.3: Threshold Levels of the Trace Elements for Production of Crop

Element	**Recommended Maximum Concentration (mg/l)**	**Remarks**
As (arsenic)	0.10	Toxicity to plants changes widely, varying from 12 mg/l for the Sudan grass to less than 0.05 mg/l for rice.
Al (aluminum)	5.0	It can trigger nonproductivity in the acid soils (pH < 5.5), but more alkaline soils at the pH > 7.0 will precipitate ion and remove any toxicity.
Be (beryllium)	0.10	Toxicity to plants changes widely, varying from 5 mg/l for the kale to 0.5 mg/l for the bush beans.

Co (cobalt)	0.05	Toxic to the tomato plants at around 0.1 mg/l in a nutrient solution. Tends to be deactivated by neutral and alkaline soils.
Cd (cadmium)	0.01	Toxic to beans, turnips, and beets at concentrations 0.1 mg/l in the nutrient solutions. Conservative limits suggested because of their potential for gathering in soils and plants to concentrations that might be harmful to humans.
Cu (copper)	0.20	Toxic to many plants at 0.1 to around 1.0 mg/l in the nutrient solutions.
Cr (chromium)	0.10	Not generally acknowledged as a crucial growth element. Conservative limits recommended because of a lack of information on its toxicity to the plants.
Fe (iron)	5.0	Not toxic to the plants in ventilated soils, but can back to soil acidification and the loss of accessibility of vital phosphorus and molybdenum. Overhead sprinkling might outcome in unsightly deposits on equipment, plants, and buildings.
F (fluoride)	1.0	Inactivated by alkaline and neutral soils.
Li (lithium)	2.5	Tolerated by most of the crops up to 5 mg/l; mobile in the soil. Toxic to citrus at the low concentrations (<0.075 mg/l). Acts correspondingly to boron.
Mo (molybdenum)	0.01	Not toxic to the plants at normal concentrations in water and soil. It can be toxic to the livestock if forage is developed in soils having high concentrations of accessible molybdenum.
Mn (manganese)	0.20	Toxic to many crops at a few-tenths to the few mg/l, but normally only in the acid soils.
Ni (nickel)	0.20	Toxic to many plants at 0.5 mg/l to 1.0 mg/l; decreased toxicity at alkaline or neutral pH.
Pd (lead)	5.0	It can prevent plant cell growth at high concentrations.
Sn (tin)	2.00	High dose of Sn can result in stomachaches, anemia, kidney problems

Se (selenium)	0.02	Toxic to many plants at concentrations 0.025 mg/l and toxic to the livestock if forage is developed in soils with comparatively high levels of added selenium. A vital element to animals but in low concentrations.
Ti (titanium)		Efficiently excluded by plants; particular tolerance unknown.
W (tungsten)		Tungsten is not considered toxic in smaller concentrations
V (vanadium)	0.10	Toxic to several plants at comparatively low concentrations.
Zn (zinc)	2.0	Toxic to numerous plants at widely changing concentrations; decreased toxicity at pH > 6.0 and in the fine-textured or organic soils.

Source: National Academy of Sciences (1972); Pratt (1972).

The maximum concentration is centered on the rate of water application which is constant with good irrigation practices. If the rate of water application greatly surpasses this, the maximum concentrations must be attuned downward accordingly. No adjustment must be made for the application rates of less than 10,000 m^3 per hectare annually. The given values are for water used on an endless basis at one site (Figure 3.1).

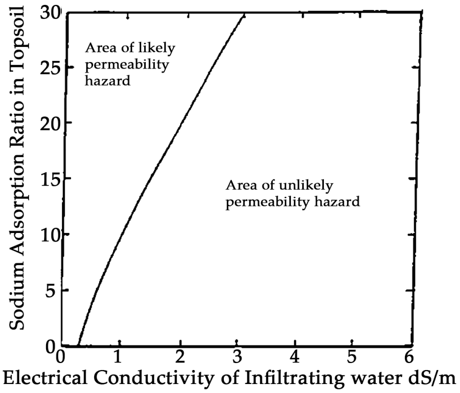


Figure 3.1: Threshold values of sodium (Na) adsorption ratio and the total salt concentration on the soil permeability hazard (Rhoades, 1982).

Source: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.470.8910&rep=rep1&type=pdf.

3.5. HEALTH SAFETY MEASURES IN AQUA-CULTURAL UTILIZATION OF WASTEWATER

The measures taken to safeguard health in aquacultural utilization of wastewater are similar to in agricultural utilization, namely crop restriction, wastewater treatment, control of wastewater application and the human exposure control and advertising of hygiene. For the safety of workers in the aquaculture ponds, the water quality is of paramount significance, as is in respect of contamination of the fish or plants developed in excreta-fertilized or the wastewater ponds (Strauss and Blumenthal, 1990). Transmission of the pathogens can take place through individuals handling and preparing polluted aquatic plants or fish, which make the human exposure control and cleanliness important characteristics of the aquaculture programs. The treatment made practical to excreta, wastewater, or night soil before introduction to the aquaculture pond and rate of the waste application will normally have an impact on water quality in the pond.

3.5.1. Special Apprehensions in Aqua-Cultural Utilization of Human Wastes

Numerous human expelled helminthic pathogens, when discharged to the aquaculture ponds, can comprise aquatic plants or fish as intermediate hosts. Strauss (1985) has registered the trematode infections given below as being able to transmit in this way:

1. Clonorchis;
2. Opistorchis;
3. Heterophys;
4. Metagonimus; and
5. Diphyllobothrium.

However, he specified that only clonorchiasis and the closely associated opisthorchiasis have been transferred via fish grown in wastewater or excrete-fertilized ponds. The first stage of development of the pathogens takes place in particular snails or copepods, with fish playing the role of a second intermediate host. The helminthic infections have substantial public health significance in Asia, where fish are occasionally eaten raw. Strauss also pointed that helminthic pathogens Fasciola and Fasciolopsis have the similar pattern of the life cycle but are dependent on aquatic plants like water chestnut, water bamboo, and watercress, as the secondary intermediate hosts onto which the free-swimming cercariae become fixed and where they encyst (Boyd, C. E., and Massaut, 1999).Fish grown in wastewater or excreta-fertilized ponds might also become polluted with viruses and bacteria and act as a possible source of transmission of the infection if the fish is eaten undercooked or raw. Pathogenic viruses and bacteria might be carried passively on scales of the fish or in the gills, intraperitoneal fluid, muscle, or digestive tract. Strauss (1985) studied the restricted literature on expelled bacteria and virus existence in fish and determined that:

1. Invasion of the fish muscle by bacteria is possible to take place if the fecal coliforms and salmonellae concentrations in the ponds are greater than 10^4 and 10^5 per 100 mL, respectively;
2. The potential for the muscle invasion rises with the exposure duration of the fish to polluted pond water;
3. A little gathering of enteric microorganisms and the pathogens on, or infiltration into, eatable fish tissue takes place when the concentration of fecal coliform in the pond water is usually below 10^3 per 100 mL;
4. Even at the lower pond water pollution levels, high concentrations of pathogen might be existent in the digestive tract and intraperitoneal fluids of the fish;
5. Pathogen invasion of kidney, spleen, and the liver has been perceived.

3.5.2. Quality Guidelines for Health Safety in Using Human Wastes for the Aquaculture

Because only inadequate experimental and the field data on health effects of the sewage-fertilized aquaculture are accessible, the WHO Scientific Group on the Health Aspects of Utilization of the Treated Wastewater for Aquaculture and Agriculture could predict only uncertain bacterial guidelines for quality of the aquaculture pond water. The uncertain bacterial guideline-recommended is the geometric mean number of the fecal coliforms of $\leq 10^3$ per hundred ml (WHO, 1989). Moreover, in view of dilution of the wastewater which usually takes place in aquaculture ponds, the ambient bacterial pointer concentration could be accomplished, the Scientific Group recommended, by treating the wastewater fed to the ponds to a certain level of 10^3 to 10^4 fecal coliforms/100 ml. Such kind of a guideline should confirm that invasion of the fish muscle is prohibited but pathogens may gather in the digestive tract and the intraperitoneal fluids of fish. This may then cause a health risk, via cross-contamination of the fish flesh or other eatable parts and transmission to the consumers, if the standards of cleanliness in preparation of fish are inadequate. High standards of cleanliness during handling of fish and, particularly, gutting are essential and cooking of the fish is a significant health safeguard. Similar contemplations apply to the preparation and cooking of the aquatic plants (Macintosh, 1982; Han et al., 2019) (Table 3.4).

Table 3.4: Bacteriological Quality of the Fish from Excreta-Reutilization Systems

Total Aerobic Bacterial Concentration in Fish Muscle Tissue, Bacteria/g	Fish quality
> 50	Unacceptable
10–30	Medium
0–10	Very good

Source: Buras et al. (1985, 1987).

Buras et al. (1985, 1987) have questioned the fecal coliforms value as bacterial pointers for the fish muscle as, in their study; they haven't detected always, while total aerobic bacteria were. They suggested that the total aerobic bacteria must be the pointers on grounds that, if these pointers were noticeable in the fish, there existed a chance that the pathogenic bacteria might also be present. Therefore, the bacteriological standards for the fish grown in wastewater and excreta-fertilized ponds were suggested by Buras et al. (1987). A more current State of the Art Review of Reutilization of Human Excreta in Aquaculture (Edwards, 1985, 1990) debated this issue and recommended that it was improbable that the fish will be of an intolerable bacteriological quality when grown in the excreta-fed ponds that are quite well-managed from an aqua-cultural viewpoint to yield good fish growth. That is, the fish ponds overloaded with excreta at the level which triggers to the growth of a comparatively large biomass of the phytoplankton, acting as the natural food for fish, but with sufficient levels of the dissolved oxygen preserved in the water, for fish, should yield fish with suitable bacteriological quality (Jagals and Steyn, 2002).

Transmission of helminthic infections clonorchiasis and the fasciolopsiasis take place only in particular areas of Asia and can also be stopped only by confirming that no trematode eggs come in the pond or by the snail control. Similar contemplations apply to control of the schistosomiasis in the areas where the disease is endemic. The Scientific Group (WHO, 1989) suggested a suitable helminth quality standard for all of the aquacultural utilization of wastewater as the lack of feasible trematode eggs.

REFERENCES

1. Angelakis, A. N., Do Monte, M. M., Bontoux, L., & Asano, T., (1999). The status of wastewater reuse practice in the Mediterranean basin: need for guidelines. *Water Research*, *33*(10), 2201–2217.
2. Baker, J. L., & Laflen, J. M., (1983). Water quality consequences of conservation tillage: New technology is needed to improve the water quality advantages of conservation tillage. *Journal of Soil and Water Conservation*, *38*(3), 186–193.
3. Bartone, C. R., & Arlosoroff, S., (1987). Irrigation reuse of pond effluents in developing countries. *Water Science and Technology*, *19*(12), 289–297.
4. Blumenthal, U. J., Abisudjak, B. A. K. I. R., Cifuentes, E., Bennett, S., & Ruiz-Palacios, G., (1991). Recent epidemiological studies to test microbiological quality guidelines for wastewater use in agriculture and aquaculture. *Public Health Reviews*, *19*(1–4), 237–242.
5. Blumenthal, U. J., Mara, D. D., Peasey, A., Ruiz-Palacios, G., & Stott, R., (2000). Guidelines for the microbiological quality of treated wastewater used in agriculture: Recommendations for revising WHO guidelines. *Bulletin of the World Health Organization*, *78*, 1104–1116.
6. Blumenthal, U. J., Strauss, M., Mara, D. D., & Cairncross, S., (1989). Generalized model of the effect of different control measures in reducing health risks from waste reuse. *Water Science and Technology*, *21*(6–7), 567–577.
7. Bouwer, H., & Idelovitch, E., (1987). Quality requirements for irrigation with sewage water. *Journal of Irrigation and Drainage Engineering*, *113*(4), 516–535.
8. Boyd, C. E., & Massaut, L., (1999). Risks associated with the use of chemicals in pond aquaculture. *Aquacultural Engineering*, *20*(2), 113–132.
9. Buras, N., Duek, L., & Niv, S., (1985). Reactions of fish to microorganisms in wastewater. *Appl. Environ. Microbiol., 50*, 989–995.
10. Buras, N., Duek, L., Niv, S., Hepher, B., & Sandbank E., (1987). Microbiological aspects of fish grown in treated wastewater. *Water Research, 21*, 1–10.
11. Carr, R. M., Blumenthal, U. J., & Duncan Mara, D., (2004). Guidelines for the safe use of wastewater in agriculture: Revisiting WHO

guidelines. *Water Science and Technology*, *50*(2), 31–38.

12. Charles, K. J., Ashbolt, N. J., Roser, D. J., McGuinness, R., & Deere, D. A., (2005). Effluent quality from 200 on-site sewage systems: Design values for guidelines. *Water Science and Technology*, *51*(10), 163–169.
13. Cho, C. Y., & Bureau, D. P., (1997). Reduction of waste output from salmonid aquaculture through feeds and feeding. *The Progressive Fish-Culturist*, *59*(2), 155–160.
14. Choudhary, M., Bailey, L. D., & Grant, C. A., (1996). Review of the use of swine manure in crop production: effects on yield and composition and on soil and water quality. *Waste Management and Research*, *14*(6), 581–595.
15. Edwards, P., (1985). Aquaculture, A component of low cost sanitation technology. *World Bank Technical Paper Number 36*, (pp. 1–30). Integretated Resource Recovery Series. The World Bank, Washington DC.
16. Edwards, P., (1990). *Reuse of Human Excreta in Aquaculture, a State of-the-Art Review* (Vol. 1, pp. 1–33). Draft Report. World Bank, Washington DC.
17. Ensink, J. H., & Van, D. H. W., (2009). Implementation of the WHO guidelines for the safe use of wastewater in Pakistan: Balancing risks and benefits. *Journal of Water and Health*, *7*(3), 464–468.
18. FAO, (1977). Crop water requirements. In: Doorenbos, J., & Pruitt, W., (eds.), *Irrigation, and Drainage* (Vol. 24, pp. 139–144). FAO, Rome.
19. FAO, (1979). Yield response to water. In: Doorenbos, J., & Kassam, A. H., (eds.), *Irrigation, and Drainage* (Vol. 33, pp. 200–203). FAO, Rome.
20. FAO, (1985). Water quality for agriculture. In: Ayers, R. S., & Westcot, D. W., (eds.), *Irrigation, and Drainage FAO* (Vol. 28, pp. 170–174), Rome.
21. FAO, (1988). Irrigation practice and water management. In: Doneen, L. D., & Westcot, D. W., (eds.), *Irrigation and Drainage* (Vol. 1, pp. 66–71), FAO, Rome.
22. Han, P., Lu, Q., Fan, L., & Zhou, W., (2019). A review on the use of microalgae for sustainable aquaculture. *Applied Sciences*, *9*(11), 2377.
23. Harwood, V. J., Levine, A. D., Scott, T. M., Chivukula, V., Lukasik, J., Farrah, S. R., & Rose, J. B., (2005). Validity of the indicator organism paradigm for pathogen reduction in reclaimed water and public health

protection. *Appl. Environ. Microbiol.*, *71*(6), 3163–3170.

24. Havelaar, A., Blumenthal, U. J., Strauss, M., Kay, D., & Bartram, J., (2001). Guidelines: The current position. *Water Quality: Guidelines, Standards, and Health*, 1, 17–42.
25. Hespanhol, I., & Prost, A. M. E., (1994). WHO guidelines and national standards for reuse and water quality. *Water Research*, *28*(1), 119–124.
26. Jagals, P., & Steyn, M., (2002). *A Review of the Applicability of the South African Guide for the Permissible Utilization and Disposal of Treated Sewage Effluent in Agriculture and Aquaculture* (Vol. 1, pp. 1–30). Water Research Commission.
27. Jan, F. A., Ishaq, M., Khan, S., Ihsanullah, I., Ahmad, I., & Shakirullah, M., (2010). A comparative study of human health risks via consumption of food crops grown on wastewater irrigated soil (Peshawar) and relatively clean water irrigated soil (lower Dir). *Journal of Hazardous Materials*, *179*(1–3), 612–621.
28. Kladivko, E. J., Frankenberger, J. R., Jaynes, D. B., Meek, D. W., Jenkinson, B. J., & Fausey, N. R., (2004). Nitrate leaching to subsurface drains as affected by drain spacing and changes in crop production system. *Journal of Environmental Quality, 33*(5), 1803–1813.
29. Macintosh, D., (1982). Fisheries and aquaculture significance of mangrove swamps, with special reference to the Indo-West Pacific region. *Recent Advances in Aquaculture, 1*, 4–85.
30. Madera, C. A., Silva, J., Mara, D. D., & Torres, P., (2009). Wastewater use in agriculture: Irrigation of sugar cane with effluents from the Cañaveralejo wastewater treatment plant in Cali, Colombia. *Environmental Technology*, *30*(10), 1011–1015.
31. National Academy of Sciences and National Academy of Engineering, (1972). *Water Quality Criteria* (pp. 589–592). US Environmental Protection Agency, Washington DC. Report No. EPA-R373–033.
32. Paltiel, O., Fedorova, G., Tadmor, G., Kleinstern, G., Maor, Y., & Chefetz, B., (2016). Human exposure to wastewater-derived pharmaceuticals in fresh produce: A randomized controlled trial focusing on carbamazepine. *Environmental Science and Technology*, *50*(8), 4476–4482.
33. Peasey, A. E., (2000). *Human Exposure to Ascaris Infection Through Wastewater Reuse in Irrigation and its Public Health Significance* (Vol. 1, pp. 1–100). Doctoral dissertation, London School of Hygiene

and Tropical Medicine.

34. Pratt, P. F., (1972). Quality criteria for trace elements in irrigation waters. *California Agricultural Experiment Station, 1,* 40–46.
35. Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P. G., Drechsel, P., Bahri, A., & Minhas, P. S., (2010). The challenges of wastewater irrigation in developing countries. *Agricultural Water Management*, *97*(4), 561–568.
36. Reilly, A., & Käferstein, F. J. A. R., (1997). Food safety hazards and the application of the principles of the hazard analysis and critical control point (HACCP) system for their control in aquaculture production. *Aquaculture Research*, *28*(10), 735–752.
37. Rousis, N. I., Zuccato, E., & Castiglioni, S., (2017). Wastewater-based epidemiology to assess human exposure to pyrethroid pesticides. *Environment International*, *99*, 213–220.
38. Shuval, H. I., (1991). The development of health guidelines for wastewater reclamation. *Water Science and Technology*, *24*(7), 149–155.
39. Singh, C. S., Gupta, S. K., & Ram, S., (1996). Assessment and management of poor quality waters for crop production: A simulation model (SWAM). *Agricultural Water Management*, *30*(1), 25–40.
40. Strauss, M., (1985). *Pathogen survival, Part II, Health Aspects of Night soil and Sludge Use in Agriculture and Aquaculture* (pp. 1–30). IRCWD Report No. 04/85, International Reference Centre for Waste Disposal, Dubendorf, Switzerland.
41. Strauss, M., (1991). Human waste use: Health protection practices and scheme monitoring. *Water Science and Technology*, *24*(9), 67–79.
42. Strauss, M., (1996). Health (pathogen) considerations regarding the use of human waste in aquaculture. In: *Environmental Research Forum* (Vol. 5, No. 6, pp. 83–98).
43. Strauss, M., & Blumenthal, U. J., (1990). Human waste use in agriculture and aquaculture. Utilization, practices, and health perspectives, executive summary. *International Reference Center for Waste Disposal Report*, *9*, 90.
44. Westrell, T., Schönning, C., Stenström, T. A., & Ashbolt, N. J., (2004). QMRA (quantitative microbial risk assessment) and HACCP (hazard analysis and critical control points) for management of pathogens in wastewater and sewage sludge treatment and reuse. *Water Science and*

Technology, *50*(2), 23–30.

45. WHO, (1981). *The Risk to Health of Microbes in Sewage Sludge Applied to Land* (pp. 1–30). EURO Reports and Studies No. 54, Regional Office for Europe, WHO, Copenhagen.
46. WHO, (1984). *Guidelines for Drinking Water Quality* (Vol. 1, pp. 124–130). WHO, Geneva.
47. WHO, (1989). *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture* (pp. 69–74). Technical Report No. 778, WHO, Geneva.

4

Irrigation With Wastewater

CONTENTS

4.1. INTRODUCTION

The water application to the soil to supply the humidity for the growth of a plant is known as irrigation. Irrigation is very important to increase the growth of crops and to stabilize the production of crops. In dry and semidry areas, irrigation is required for financially feasible agriculture, whereas in moist and semi-moist areas, irrigation is necessary on a need basis (Mapanda et al., 2005; Heidarpour et al., 2007).

The basic conditions at the farm level that should be fulfilled to make successful irrigated farming are following (Murillo et al., 2000; Elgallal et al., 2016):

1. The quality of water should be satisfactory;
2. Apply the requisite amount of water;
3. Suitable methods should be used for irrigation;
4. There should be a proper schedule of water application;
5. The nutrients of the plant should be controlled positively.
6. The level of the water table ought to be controlled through the adequate method of drainage;
7. The prevention of salt gathering in the root region should be assured through the method leaching (Figure 4.1).

Figure 4.1: Crops' irrigation using wastewater.

Source: https://www.fluencecorp.com/study-says-wastewater-use-in-crop-irrigation-higher-than-thought/.

The above criteria are applicable as same as when wastewater is used as the source of irrigation water (Geber, 2000; Dimitriou and Aronsson, 2004). Nutrients in the wastewater of the public and used wastewater are the best supplements of these sources as compared to traditional water sources of irrigation and therefore there is no need for additional fertilizers. Most importantly, the criteria of health and environment should be kept in mind when used effluents are the sources of irrigation water (Dimitriou and Aronsson, 2004; Pedrero et al., 2010; Zema et al., 2012).

4.1.1. Amount of Water to Be Applied

About 99% of the absorbed water of the plant is lost from the surface of the plant by the process of transpiration and evaporation. Therefore, the water and evapotranspiration (ET_c) demand for crops is equal for all practical purposes. ET_c of the crop is calculated on the base of climatic conditions and therefore it may be predicted accurately by using data of meteorological (Darwish et al., 1999; Mohammad and Mazahreh, 2003). FAO has a computer program known as CROPWAT which is used to find out the water needs for crops through the data of climate. Table 4.1 reported by Doorenbos and Kassam in which water needs of different crops is given, (FAO, 1977, 1979). The definite amount of irrigation water that is used must be accommodated for leaching need, useful rainfall, losses of application, and other aspects (Oron et al., 1991, 1995, 1999).

4.1.2. Quality of Water to Be Applied

The quality needs of irrigation water and recommendations given in this chapter are pinpointing in nature and must be modified according to the condition of the soil, regional climate, and other aspects (Filip et al., 1999; Ensink et al., 2007). Farming practices, for example, the type of crop which is cultivated, method of irrigation, and other cultivation practices, will assess the suitability and quality of irrigation water. In this chapter, we will discuss the essential farming practices whose aim will be to maximize the production of the crop when wastewater is used as irrigation water (Scott et al., 2004; Jia et al., 2006; Rusan et al., 2007).

Table 4.1: Water Requirements, Sensitivity to Water Supply and Water Utilization Efficiency of Some Selected Crops

Crop	Sensitivity to Water Supply (ky)	Water Utilization Efficiency for Harvested Yield, Ey, kg/m^3 (% Moisture)	Water Requirements (mm/Growing Period)
Cabbage	Medium-low (0.95)	12–20 head (90–95%)	380–500

Banana	High (1.2–1.35)	plant crop: 2.5–4 ratoon: 3.5–6 fruit (70%)	1200–2200
Alfalfa	Low to medium-high (0.7–1.1)	1.5–2.0 hay (10–15%)	800–1600
Bean	Medium-high (1.15)	lush: 1.5–2.0 (80–90%) dry: 0.3–0.6 (10%)	300–500
Cotton	Medium-low (0.85)	0.4–0.6 seed cotton (10%)	700–1300
Citrus	Low to medium-high (0.8–1.1)	2–5 fruit (85%, lime: 70%)	900–1200
Potato	Medium-high (1.1)	4–7 fresh tuber (70–75%)	500–700
Groundnut	Low (0.7)	0.6–0.8 unshelled dry nut (15%)	500–700
Maize	High (1.25)	0.8–1.6 grain (10–13%)	500–800
Sorghum	Medium-low (0.9)	0.6–1.0 grain (12–15%)	450–650
Safflower	low	0.2–0.5 seed (8–10%)	600–1200
Wheat	Medium high (spring: 1.15; winter: 1.0)	0.8–1.0 grain (12–15%)	450–650
Rice	High	0.7–1.1 paddy (15–20%)	350–700

Source: FAO (1979); Oroon et al. (2001).

4.1.3. Scheduling of Irrigation

A required amount of water ought to be applied to crops for achieving the highest yield before the demand of the moisture of the soil that reaches at a stage where the rate of ET_c is lower than its potential (Girona et al., 2006; Velez et al., 2007). Following equation illustrates the relationship of yields to ET_c at the actual and maximum levels:

$$1-\frac{Y_a}{Y_m}=ky\left(1-\frac{ET_a}{ET_m}\right)$$

where: ky= yield response factor; ET_a = actual evapotranspiration; ET_m = maximum evapotranspiration; Y_a = actual harvested yield; and Y_m = maximum harvested yield.

Many methods are used to find out the most favorable irrigation schedule. Factors for making the schedule of irrigation are used to find out the depth of root region, rate of ET_c, the capacity of the soils for water holding, and water quantity that is required for one-time irrigation, conditions of drainage and best methods of irrigation (Krüger et al., 1999; Grant et al., 2009).

4.1.4. Irrigation Methods

Farmers are using several methods to irrigate the crops. These different methods of irrigation range from watering of single plants through a can of water to the advanced irrigation methods. For moisturizing of the soil, these methods may be classified into five different groups (Abou-Rass and Piccinino, 1982; Cetin and Bilgel, 2002):

1. **Flood Irrigation:** In this method, water is used to irrigate the whole field as the water penetrates the soil (for example, borders, basins, contour flooding, wild flooding, etc.).
2. **Furrow Irrigation:** In this method, we apply water between furrow (for example, contour furrows, corrugations, graded, and level furrows, etc.). In this method, plant roots get water through capillary action.
3. **Sprinkler Irrigation:** In this method, we apply water to the plants in the form of a spray and its benefit on the soil is like the rain (for example, traveling sprinklers, portable, and solid set sprinklers, center-pivot systems, spray guns, etc.). The speed of the sprinkler should be controlled so that it does not shower excess water on the surface of the soil.
4. **Sub-Irrigation:** In this method, we apply water beneath the root region so that it damps the root region by the capillary action (e.g., subsurface irrigation canals, buried pipes, etc.). For this purpose, we use the buried pipes or the deep surface of canals.
5. **Localized Irrigation:** By this method, we apply water to each plant one by one or by a group of plants so that it damps the plant and the plant's root only (for example, bubblers, micro-sprinklers, drip irrigation, etc.). The rate of application should be controlled to fulfill the needs of ET_c as the percolation losses can be minimized (Pereira, 1999; Onder et al., 2005).

The following table shows some essential characteristics of chosen irrigation systems that are reported by Doneen and Westcot (FAO, 1988) (Table 4.2).

Table 4.2: Basic Features of Some Selected Irrigation Systems

Irrigation Method	**Crops**	**Topography**	**Remarks**
Rectangular checks (levees	Orchard	Land slopes able of being graded so single or multiple tree basins will be leveled within 6 cm	This method is used for the lands whose rate of water intake is either a relatively high or low. The efficiency of water application is about 40 to 60%.
Sprinkler	All crops	Undulating 1->35% slope	Costs of operation and maintenance of this method are high. This method is good for sandy or very irregular lands in good markets and high production zone. This method is suitable for low power costs. this method is useful in rough or steep topography regions. This method is good for the regions where there is high rainfall and a small amount of water is required. The efficiency of water application is about 60 to 70%.
Widely spaced Borders	Alfalfa and other deep-rooted close-growing crops and orchards	Land slopes able of being graded to less than 1% slope and preferably 0.2%	A suitable method for applying water to the close-growing crops where geographical circumstances are favorable. For smooth soil, evaluation is needed in the water system and also this type of evaluation is desirable but not important on slopes of more than 0.5%. There should be minor changes in the grade and reverse grades should be avoided. Cross slops are allowable when we are restricted to differences in height between border strips of 6 cm to 9 cm. the efficiency of water application is about 45 to 60%.

Graded contour furrows	Row crops and fruit	Variable land slopes of 2–25% but preferable less	This method is used for row crops on steep land, although it is risky due to erosion from heavy rainfall. This method is not suitable for the soil that has many cracks. the direction of irrigation has the actual grade between 0.5 to 1.5%. There is no grading is essential beyond the removal of rushed ridges and filling gullies. The efficiency of water application is about 50 to 65%.
Localized (drip, trickle, etc.)	Row crops or Fruit	Any topographic condition appropriate for row crop farming	Perforated water pipes are used to moist the surface of the soil at the base of fruit trees or vegetable plants. In Israel, it is being used with saline irrigation water. But it is in the developing stage. The efficiency of water application is about 75 to 85%.
Sub-irrigation	Shallow rooted crops for example grass or potatoes	Smooth-flat	In this method, there is a requirement of the water table, accurate leveling very permeable, and subsoil conditions. This method is adapted in very few areas. The efficiency of water application is about 50 to 70%.

Source: FAO (1985, 1988).

4.1.5. Leaching

In irrigated agriculture, an excess amount of irrigation water is applied which penetrates through the root area so that it removes the extra salts which have made due to ET_c from the original water of irrigation (Bernstein and Francois, 1973; Bauder and Brock, 2001). The process which is used to remove the salts from the root area is knowns as leaching and the irrigation water which removes the extra salts is known as the leaching fraction (LF).

$$\text{Leaching Fraction} = \frac{\text{Depth of water leached below the root zone}}{\text{Depth of water applied at the surface}}$$

The control of extra salt of the root area by efficient leaching becomes more significant like the water of irrigation becomes saltier (Snyder et al., 1984; Gheysari et al., 2009) (Figure 4.2).

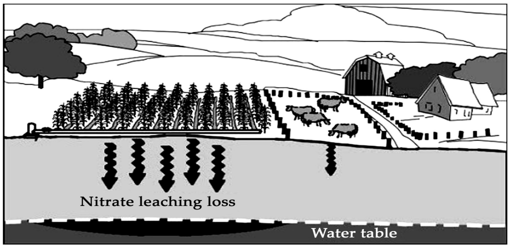


Figure 4.2: Nitrate leaching due to wastewater irrigation.

Source: http://croptechnology.unl.edu/pages/informationmodule.php?idinformationmodule=1130447123&topicorder=5&maxto=13&minto=1.

4.1.6. Drainage

The removal of the extra amount of water from the surface of the land is known as drainage and by doing so, it allows the most favorable development of plants. Surface drainage is the removal of an extra amount of water of surface whereas subsurface drainage is the removal of an extra amount of water from underneath the soil surface. For a successful water system of agriculture, the significance of drainage has been illustrated in a very well way (Allen et al., 1998a, b). Semi-dry and dry regions must avoid secondary salinization. In semidry and dry regions, when the natural internal drainage of the land is not satisfactory then the level of the water table will rise with the application of water. When the level of the water table is under a few meters of the surface of the land then salts will be transported to the surface of the land by the capillary action of salty groundwater. The salts become at the surface of the soil by the evaporation of water. If the evaporation of water is not controlled, the salt formation will continue at the surface of the soil, which becomes the reason of the salinization of the soil. In these situations, subsurface drainage may control the rise of the level of the water table and thus it avoids the salinization of the soil (Rhoades et al., 1973; Svedman et al., 1986).

4.2. STRATEGIES FOR MANAGING TREATED WASTEWATER ON THE FARM

The successful use of wastewater for the production of the crop would mainly rely on the selection of suitable strategies whose aim is to get good yield and quality of the crop, maintain the productivity of soil, and protect the environment. There are many other methods are existing and for a known set of conditions, these methods will give a suitable solution. The consumer ought to know the wastewater quality and its supply, as indicated in Table 4.3, to make sure the formulation and implementation of a suitable strategy for managing the farm (Carr et al., 2011; Mizyed, 013).

The components of a suitable strategy for managing the farm for the use of wastewater will comprise of a combination of (Saliba et al., 2018):

1. The selection of irrigation method;
2. The selection of suitable management practices; and
3. The selection of crops.

When the farmer has sources of wastewater supply and amount of conventional irrigation water, then he can use both the wastewater and the conventional irrigation water in two ways that are (Qadir et al., 2015):

1. The use of these two sources one by one; and
2. By mixing wastewater and conventional irrigation water.

Table 4.3: Information Required on Effluent Supply and Quality

Information	**The Decision on Irrigation Management**
Effluent Quality	
The cations Concentration, for example Mg^{++}, Ca^{++} and Na^{+}.	For the assessment of the hazard of sodium and for taking proper actions.
The electrical conductivity of the effluent and total concentration of salt.	Selection of methods of irrigation, leaching, crops, and other managing practices.
The trace elements concentration (mainly those which are supposed to phytotoxic).	For the assessment of trace toxicities and for taking proper actions.
The toxic ions concentration, for example, Boron, heavy metals and Cl^{-}.	For the assessment of toxicities that are caused by these elements and for taking proper actions.
Fecal coliforms and levels of intestinal nematodes.	For the selection of systems of irrigation and proper crops.
Suspended sediment Levels	For the selection of a proper irrigation system and actions to avoid clogging problems.
The nutrients concentration, mainly nitrate-N.	For the adjustment of fertilizer levels, prevent over fertilization and for the selection of crops.
Effluent Supply	
The delivery rate of waste matter either like m^3 per day or liters per second.	The layout of fields, the total area that might be irrigated, and facilities and system of irrigation.

The total effluent amount should be available during the growing season of the crop.	The total area that might be irrigated at any given time.
Waste matters availability for the whole year.	The facility of storage when there is a period of non crop either at the farm or near effluent treatment plant and the use for aquaculture.
The supply mode: From the storage reservoir, waste matter is pumped by the farmer or supply at the gate of the farm.	The pumps and pipes should be installed to convey waste matter and irrigation systems.
Delivery type: on-demand, continuous or intermittent,	Irrigation systems, the layout of fields and facilities, and the schedule of irrigation.

4.3. CROP SELECTION

4.3.1. To Overcome Salinity Hazards

All the plants don't similarly respond to salinity; at high salinity of the soil, certain crops may be able to produce satisfactory yields than other crops. This is the main reason that certain crops can make required osmotic changes and remove extra water from salty soil.

The adjustment of the salinity of soil is the valuable ability of a crop. In the regions where the salinity of soil may not be restricted at an adequate salinity concentration for the crop that is grown, so choose another crop that has the ability to tolerant the salinity of the soil and can produce cost-effective yields. The salt tolerance of crops is within a range of 8 to 10 fold. This broad range of salt tolerance of the soil allows for the better utilization of salty water, earlier it was considered that salty water cannot be used. It widely explains that adequate water salinity range (EC_w) is considered appropriate for irrigation (Ashraf and Saeed, 2006; Choudhary et al., 2011).

If the exact replacements or patterns of crops for the new regions are not recognized, then the leaching need should be dependent on the tolerance of the crops of that area.

In such cases, where the salinity of the soil may not be controlled within adequate limits of chosen sensitive crops, moving towards the high salt-tolerant crops would increase the potential for the production in the fields. If we are not sure about the impact of effluent salinity on the production of the crop, the empirical study must be done to show the practicability of irrigation and the position for monetary accomplishment (Datta and De Jong, 2002; Haque, 2006).

4.3.2. To Overcome Toxicity Hazards

An issue of salinity is dissimilar from the issue of toxicity because toxicity happens in the plant itself and is not due to the lack of water. Toxicity occurs when plants take up specific ions from the water of the soil and gather these ions in the leaves of the plant during the transpiration of water at that level where the plant is spoiled. The rate of plant harm is based on time, the use of crop water, the poisonous material concentration, and tolerance of crop and, if the plant harm is very high then yield of the crop is decreased (Rao et al., 1993; Conner and Jacobs, 1999). Those poisonous ions which are common in the water of irrigation include sodium, boron, and chloride, all of these poisonous ions would be incorporated in sewage. Each toxic ion may cause damage separately or in the grouping. These poisonous ions are not equally responsive to all crops. If poisonous materials concentration in any crop that is high enough then the signs of toxicity may come out in nearly any crop. Mostly, toxicity complicates a salinity issue, while it can come out when there is not a problem of salinity.

When we moisturized the plants by the method of sprinkler irrigation then the harmful ions of chloride and sodium may be directly absorbed into the plant throughout the leaves. This usually happens when there is a period of low humidity and high temperature. If there is absorption by Leaf then it increases the rate of the gathering of a poisonous ion in the leaf and can be a main toxicity source (Pandey et al., 2018).

Though urban effluent can consist of heavy metals at a concentration which would increase the prominent levels in the soil and may cause unwanted materials additions in the tissues of the plant and it reduce the growth of the crop. Heavy metals are easily fixed and deposited by wastewater in soils with regular irrigation and can either make them unproductive or the product that is not usable. The use of wastewater studies has revealed that over 85% of the heavy metals that are applied are gathered mostly on the surface of the soil. The rate at which the accumulation of heavy metals in the soil has a poisonous impact on the crops. The usage of any wastewater project must comprise the monitoring of plants and soil for poisonous materials (Salt et al., 1995).

4.4. SELECTION OF IRRIGATION METHODS

Under typical conditions, the selection of the kind of irrigation method would be based on the farmer’s ability to supervise the system, crops that are going to grow, soil, irrigation method costs, climate, and the conditions of water supply. However, other considerations, for example, plants pollution and produced products, environment, and the farmworkers, and toxicity and salinity hazards, should be considered when we are using effluent as irrigation source(Robertson and Wang, 2004; Karami, 2006). When we choose a proper irrigation method then we have a significant range for decreasing the unwanted impact of the usage of wastewater in irrigation.

When we are going to choose the irrigation method for the usage of wastewater following technical factors should be kept in mind:

1. The damping of fruits, foliage, and aerial parts—the delivery of salts, pollutants, and water in the soil;
2. The crops choice;
3. The potential for polluting the environment and farmworkers;
4. The method with which high potential of the soil water might be sustained;
5. The application effectiveness,

Table 4.4 shows an overview of such factors with four extensively experienced irrigation methods, which are drip, furrow, sprinkler, and border irrigation.

Table 4.4: Evaluation of Common Irrigation Methods with the Use of Treated Wastewater

Parameters of Evaluation	**Drip Irrigation**	**Furrow Irrigation**	**Sprinkler Irrigation**	**Border Irrigation**
1. Salt gathering in the root region with regular applications	The movement of salt is radial beside the direction of the movement of water. A salt block is created among drip points	Salts gathered in the ridge which might damage the crop	The movement of salt is downwards and the root region is not liable to gather salts	The movement of salt is perpendicularly downwards and are not liable to gather in the root region
2. Foliar damping and resulting damage of leaf consequent in low yield	There is no foliar damage happen by this irrigation method	There is no foliar damage because the crop is planted on the ridge	There is harsh leaf injury may happen to result in a major loss of yield	Some bottom leaves of the plant can be affected but the injury is not so much serious that it reduces the yield

3. Suitability to control salty wastewater without major loss of yield	Excellent to good. Nearly all the crops may be grown with a small decrease in yield	Fair to medium. With good drainage and management, satisfactory yields are achievable	Poor to fair. Mostly crops suffer from the damage of leaf and resulting low yield	Fair to medium. Good drainage and irrigation practices may produce an adequate amount of yield
4. Ability to keep the high potential of soil water	Ability to keep the high potential of soil water during the season of growing and reduce the salinity effect	Plants can be subject to water stress among irrigation systems	There is no ability to keep the high potential of soil water during the season of growing	Plants can be subject to water stress among irrigation systems

Source: Kandiah (1990b).

A border irrigation system requires full soil surface coverage with the treated waste matter and is not usually a competent irrigation method. This method of irrigation would also pollute growing crops of vegetables close to the soil and root crops and more than any other method would open farmworkers to the waste matter. By keeping in mind the health and water conservation factors, we concluded that the border irrigation method with effluent is not suitable.

The method of furrow irrigation does not humidify the whole surface of the soil. This type of irrigation method may decrease the pollution of the crop because plants are grown on the edges of the crinkle, but there may not full protection guarantee of the health. Farmworkers' pollution is theoretically medium to high, but it is based on automation. If the waste matter is moved by, using pipes and transported into entity furrows through gated pipes then there is a risk to the workers of irrigation would be negligible (Montazar and Behbahani, 2007).

Water quality is not very much affected by the efficiency of the methods of surface irrigation generally, furrows, basins, and borders, while the risk of health in such systems is certainly considered. If the waste matter includes large numbers of suspended solids, certain issues may occur and this settles and limits the flow of pipes, gates, channels, and appurtenances to be carried. Many of these issues would be resolved by using treated sewage. Leveling of land ought to be carried out with awareness to prevent the surface irrigation of heavy waste matter, and sufficient land grades ought to be given.In general, the method of sprinkler irrigation is more effective in the use of water because greater application consistency may be accomplished. Such methods of sprinkle irrigation can pollute fruit trees, soil, farmworkers, and crops. Furthermore, contaminants found in the aerosolized waste matter can be moved through wind and generate the risk of health to the neighboring population. By the comparison of automated or mechanized systems and manually moved sprinkler systems, it revealed that mechanized systems have greater capital and labor costs. To attain the uniform moisturization and to avoid extra head losses, the leveling of rough land is very important for the sprinkler systems. By comparison, of surface irrigation systems and sprinkler systems, it shows that water quality mostly affects the sprinkler systems, primarily due to leaf burns, and residue gathering in pipes, blockage of orifices in sprinkler heads, and phytotoxicity by water salinity and holds extra poisonous elements, delivery, and valves systems. Secondary treatment of effluent has usually been found to make a waste matter appropriate for delivery with sprinklers; the effluent mustn't be too salty. Other preventive measures are taken, for example, treatment with micro strainers or granular filters and diameters extension of nozzle orifice not smaller than 5 millimeters (Draginčić and Vranešević, 2014).

The restricted water system may generate the highest yield of the crop, especially when the surface of the soil is secured with plastic sheets or with other materials and by the effective use of wastewater, and also it gives the highest level of health security for consumers and workers. On the other hand, drip, and trickle water systems are costly and need a high wastewater quality to avoid blockage of the emitters by which wastewater is gradually discharged into the soil. The growth of biological organisms or solids in wastewater at the delivery pipes may cause issues and we can overcome these issues in Cyprus by gravel filtration of wastewater and daily line washing-out (Stylianou and Papadopoulos, 1988). The Bubbler water system is a procedure that is developed for the localized water system of tree crops in which small emitter holes are not required however, the cautious setting is needed for its good use (Hillel, 1987) (Table 4.5).

Table 4.5: Water Quality and Clogging Potential in Drip Irrigation Systems

Potential Problem	**Units**	**Degree of Restriction on Use**		
		None	**Slight to Moderate**	**Severe**
Chemical				
pH		< 7.0	7.0–8.0	> 8.0
Manganese	mg/l	< 0.1	0.1–1.5	> 1.5

Dissolved solids	mg/l	< 500	500–2000	> 2000
Hydrogen sulphide	mg/l	< 0.5	0.5–2.0	> 2.0
Iron	mg/l	< 0.1	0.1–1.5	> 1.5
Bacterial populations	number/ml	< 10000	10 000–50 000	> 50000
Biological	maximum			
Physical				
Suspended solids	mg/l	< 50	50–100	> 100

Source: Nakayama (1982).

The key benefits of the trickle irrigation system with the comparison of other systems are:

1. **High Efficiency of Irrigation:** Wind drift or losses of transport, minimum losses of drainage and no covering interception.
2. Improved crop yield and growth obtained through optimization of the nutrients, air systems in the root region, and water.
3. **Low Requirements of Energy:** The trickle system needs a pressure of water just 100 to 300 kilopascal (1 to 3 bar).
4. **Low Labor Requirements:** It may be easy to automate the trickle system, even though to permit joint fertilization and irrigation (occasionally terms fertigation).
5. Minimum contact among wastewater and farmworkers.

The trickle irrigation systems have high capital cost and also another restrictive issue for their use is that these systems are just suitable for the row crop irrigation. The relocation of subsurface systems may be costly.

The decision on the choice of the irrigation systems would be cost-effective however the health issues linked with these irrigation methods would also be considered. The possible health control measures that can be taken by the choice of the method of effluent application as well as with the treatment of effluent, human exposure control, and choice of the crop. Every measure you take would interrelate with the others and therefore a decision on the choice of the irrigation system affect the requirements of effluent treatment, the choice of crop, and human exposure control (such as trickle irrigation system decides the row crops). Simultaneously, the feasibility of irrigation techniques would rely on the selection of an irrigation system and the choice of the crop could be restricted if the treatment of effluent has been determined already before the utilization of effluent.

4.5. FIELD MANAGEMENT PRACTICES IN WASTEWATER IRRIGATION

Crop, soil, water, and operational management practices, as well as measures to shield farmworkers, play a vital role in the effective utilization of sewage wastewater for irrigation.

4.5.1. Water Management

Mostly treated wastewater is not very salty, the normal range of wastewater salinity is between 500 and 200 mg/l (EC_w = 0.7–3.0 dS/m). On the other hand, there can be cases where the concentration of salinity reaches the amount of 2000 mg/l. In any case, to avoid salinization proper water management methods would need to be practiced, regardless of whether the content of the salt in the effluent is low or high (Brouwer et al., 1985, 1988). It is attractive by noticing that even the use of nonsalty effluent, for example, one containing the salinity range between 200 to 500 mg/l, when used at the normal rate of irrigation of 20,000 m^3 per hectare, would increase the amount of salt to the soil about 2 to 5 tons annually. The issues of salinity may rise quickly if the root region is not washed out by the method of leaching and salt from the soil is not removed by successful drainage. Therefore, drainage, and leaching are two essential methods in the management of water to prevent soil salinization. Following are the main factors in management methods of water (Cai et al., 2003; Fereres et al., 2003):

1. Drainage;
2. Mixing of effluent with other water sources;
3. Leaching;
4. Alternating treated effluent with other water supplies; and
5. Irrigation timing.

4.5.2. Land and Soil Management

At the field level, different soil and land management methods may be implemented to address the sodicity, toxicity, health issues, and salinity that could be linked with the utilization of treated effluent (Follett, 2001; Sojka et al., 2007).

4.5.2.1. Land Development

Necessary steps may be adopted during the early phases of on-farm development of the land to reduce the potential risks that can arise from the utilization of effluent. These steps would need to be well designed, developed, and implemented because these operations are costly and, mostly, one time.

4.5.2.2. Land Grading

Ranking of land is critical for achieving better application evenness from the methods of surface irrigation and generally adequate irrigation efficiencies. If the effluent is salty then the irrigated land must be properly graded. Salts build up in those high spots which contain too small leaching and absorption of water while water gathers in the low spots and it becomes the reason for crusting of soil and water logging (Murtaza et al., 2006).

4.5.2.3. Deep Cultivation

Soil irrigation is very difficult in certain regions where the soil is in the form of layers. In stratified soils, layers of sand, hardpan, or clay often hinder or avoid free water transportation in the root region. This would saturate the region of root and also allow the salts gathering in the root region (Jabro et al., 2008).

4.5.3. Crop Management and Cultural Practices

Different crop and cultural management methods that apply to the utilization of salty water would also apply to the utilization of wastewater. These methods aim to avoid crop damage due to salt gathering around the plants and in the root region and modify agrochemical and fertilizer uses to match the quality of the crop and the wastewater (Dorais, 2003).In many crops, the salinity of soil more severely affects the germination of seed than other phases of a crop's growth. The effects have marked in the crops that are furrow-irrigated, where the water is moderate to extremely salty. This is due to the water in the ridges goes upwards by capillary action, bringing salts with it. Salt accumulation occurs in the ridges if the water is evaporated or absorbed (Campbell et al., 1991; Gavito and Miller, 1998). The maximum concentration of salts happens in the middle of the ridge while the minimum salt concentration occurs along the ridge shoulders. An effective way to solve this issue is by ensuring that the low salinity soil should be around the germination of seed. The harm to seed germination may be decreased by the management of water systems, suitable planting practices, and shapes of the ridge. Several definite methods comprise (Colbach and Debaeke, 1998):

1. Irrigation of alternate rows to allow the salts to pass away from the solo seed row;
2. Use sloping beds for the plantation of seeds on the sloping side however it should be above the line of the water; and
3. Planting on both shoulders of the ridge in the case of double row planting or on the single shoulder in solo row planting.

4.6. PLANNING FOR WASTEWATER IRRIGATION

4.6.1. Central Planning

The policy of the government on the usage of wastewater in agricultural land would have a significant impact on control mechanisms that may be accomplished by the careful choice of treated effluent crops and sites. A decision is made to assure the accessibility of the treated wastewater to farmers for unregulated irrigation or to the irrigation of public parks and metropolitan green regions with wastewater would eliminate the options of getting the benefit by careful choice of the sites, methods of irrigation and crops to minimize the health hazards and minimize the effects on the environment.

On the other hand, if a Government determines that wastewater irrigation would be implemented only in particular controlled regions, even though the choice of the crop is not restricted (specifically, unregulated irrigation within these regions is permitted), access of the people to the irrigated regions would be prohibited and several precautions may be used. The greatest protection against health hazards and unpleasant effects on the environment would certainly be accomplished through restraining usage of wastewater to controlled irrigation on regulated regions where the people have no right of entry however by commanding limitations on wastewater irrigation by planters if appropriately applied, a level of control may be achieved (Zhovtonog et al., 2005).

Johnson and Cobham (1988) have indicated that the methods used for the preparation of wastewater irrigation plans are identical to those methods that are used in other types of resource scheduling and outlined the major social, economic, and physical aspects. Johnson and Cobham also suggested that different main tasks or problems may have a major impact on the vital accomplishment of wastewater irrigation like this (Gordon et al., 1995):

1. The priority is given to the aspects of people health safety and the

degree of risk considered;

2. The selection of multiple-use or solo-use methods;
3. Administrative and organizational arrangements for handling the resource, choosing, and executing the effluent utilization program;
4. The degree of understanding the potential for forestry resource creation; and
5. The parameters followed when calculating plans for alternative reuse.

The implementation of the combine wastewater utilization methods is typically beneficial in terms of allowing for greater flexibility, improved financial stability and more effective usage of the wastewater across the year, while a single-use approach would result in cyclic surpluses of effluent for blocked disposal. Thus, in the selection of sites and crops, it is important to bear in mind the interest of giving regions for different plantations and crops to the effective use of the wastewater during the seasonal cycle (Li and Yang, 2005).

4.6.2. Desirable Site Characteristics

The characteristics that are crucial in determining the feasibility of the project of land clearance are the position of people's attitudes and existing land. A land specifically away from the plant of manure treatment would acquire high costs of the treated wastewater delivery to that location and therefore would not be appropriate.

Therefore, when the sewerage is designed, the land availability for the irrigation of wastewater ought to be kept in mind and plants of manure treatment ought to be situated with proper agricultural places (Schmitz et al., 2002; Kumar et al., 1992).

Such places would not be near to populated regions however, the distant land could not be socially appropriate for people if the cultural, religious, and social behaviors are contrary to the effluent irrigation methods. The health risk is a conscious problem that is due to wastewater irrigation and people fear would only be calm down by taking precautionary measures. In dry regions, the significance of using treated wastewater for agricultural purposes makes it systematic sensible in developing, planning, and managing projects for wastewater irrigation and awareness should be given to people at all phases (Thomas et al., 2004).

For the selection of location, the optimal goal is to discover a proper region where the long-lasting utilization of treated wastewater would be practicable without negative impacts on the health of people or the environment. For a specific case, it may be probable to find out many possible places within a sensible distance of the severed society and there would be a challenge to choose the proper location, taking into consideration all relevant aspects. For a specific area following essential information should be considered, if accessible:

1. Surveys of agricultural soils;
2. A map of topographic;
3. Reports and geological maps;
4. Aerial photographs;
5. Soil test results and boring logs;
6. Reports of groundwater and well logs; and
7. Other piezometric and soil data.

During the early phase of the investigation, the possible effect of the utilization of treated wastewater on any utilizable groundwater in the concerned areas must be evaluated. The ranking of the location should be on the parameters, for example, its currents usage, the location, and value of the land, and social factors, and availability, furthermore the conditions of groundwater and soil should be kept in mind.The features of the soil structure comprising a specific site are quite important for determining its sustainability for methods of wastewater utilization and irrigation. Physical parameters (for example gradation, texture, plastic, and liquid limits, etc.); water-holding capability, permeability, pH, chemical composition and salinity are among the characteristics of soil and essential for the application of wastewater and production of crops. The tentative site study may involve shallow boring of manual-auger and vegetation recognition, which would also allow the inadequate sites to be removed. Upon the removal of potential sites, every site under severe consideration will be analyzed through the on-site boring to assess the water table position, composition of the soil, and features of the soil. Piezometers must be found in every hole of the bore and this may be used for future testing of groundwater. For these site evaluation, Hall, and Thompson (1981) have defined a method, if this method implemented, it should not only permit the selection of most appropriate site between many alternatives however should also allow the effects of wastewater irrigation at the selected location. As we established a site, an important aspect of its management must be a long-lasting groundwater control system.

4.6.3. Crop Selection Issues

During the selection of the crops, a farmer typically is affected through the environment, economy, accessible management expertise, characteristics of water and soil, tradition, and labor and machinery. The level to which the selection of crops is affected by the usage of treated wastewater would rely on the quality of wastewater, the user's goal, and the policy of the Government for wastewater irrigation. Government policy would aim to reduce the health-related issues, environmental danger and it should affect the level of production correlated with the irrigation of wastewater. Rules and regulations should be practical and feasible in the view of local and national customs and environmental factors. The main aim of the developers of wastewater irrigation methods should try to obtain optimum efficiency and water management by the wastewater utilization systems and crop selection (Pereira, 1999).

A multiuse strategy solution would involve the assessment of feasible combinations of potential crop varieties on the available land. Apart from the requisite water and soil quality surveys, this would require a significant assessment level and capital budgeting activity. The daily, monthly, and yearly crop water demand must be calculated through the most suitable methods of irrigation. To determine the economic value of wastewater irrigation of different crop varieties, domestic use, local output and imports of the different crops need to be measured. The demand for the irrigation of crops should be compared with the accessible wastewater in order to ensure maximum financial and physical annual usage. Johnson and Cobham (1988) study this evaluation method for effluent usage in Kuwait, where commercial forestation was found to provide considerable potential in multiuse of the irrigation of wastewater (Wang et al., 2003).

REFERENCES

1. Abou-Rass, M., & Piccinino, M. V., (1982). The effectiveness of four clinical irrigation methods on the removal of root canal debris. *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology*, *54*(3), 323–328.
2. Allen, R. G., Pereira, L. S., Raes, D., & Smith, M., (1998a). FAO *Irrigation and Drainage Paper No. 56* (Vol. 56, No. 97, p. e156). Rome: Food and Agriculture Organization of the United Nations.
3. Allen, R. G., Pereira, L. S., Raes, D., & Smith, M., (1998b). *Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements-FAO Irrigation and Drainage Paper 56* (Vol. 300, No. 9), p. D05109). FAO, Rome.
4. Ashraf, M., & Saeed, M. M., (2006). Effect of improved cultural practices on crop yield and soil salinity under relatively saline groundwater applications. *Irrigation and Drainage Systems*, *20*(1), 111–124.
5. Bauder, J. W., & Brock, T. A., (2001). Irrigation water quality, soil amendment, and crop effects on sodium leaching. *Arid Land Research and Management*, *15*(2), 101–113.
6. Bernstein, L., & Francois, L. E., (1973). Leaching requirement studies: Sensitivity of alfalfa to salinity of irrigation and drainage waters. *Soil Science Society of America Journal*, *37*(6), 931–943.
7. Brouwer, C., Goffeau, A., & Heibloem, M., (1985). *Irrigation Water Management: Training Manual no. 1-Introduction to Irrigation* (Vol. 1, pp. 102–103). Food and Agriculture Organization of the United Nations, Rome, Italy.
8. Brouwer, C., Prins, K., Kay, M., & Heibloem, M., (1988). Irrigation water management: Irrigation methods. *Training Manual*, *9*(5), 5–7.
9. Cai, X., McKinney, D. C., & Rosegrant, M. W., (2003). Sustainability analysis for irrigation water management in the Aral Sea region. *Agricultural Systems*, *76*(3), 1043–1066.
10. Campbell, C. A., Biederbeck, V. O., Zentner, R. P., & Lafond, G. P., (1991). Effect of crop rotations and cultural practices on soil organic matter, microbial biomass, and respiration in a thin Black Chernozem. *Canadian Journal of Soil Science*, *71*(3), 363–376.
11. Carr, G., Potter, R. B., & Nortcliff, S., (2011). Water reuse for irrigation in Jordan: Perceptions of water quality among farmers. *Agricultural Water Management*, *98*(5), 847–854.

12. Cetin, O., & Bilgel, L., (2002). Effects of different irrigation methods on shedding and yield of cotton. *Agricultural Water Management*, *54*(1), 1–15.
13. Choudhary, O. P., Grattan, S. R., & Minhas, P. S., (2011). Sustainable crop production using saline and sodic irrigation waters. In: *Alternative Farming Systems, Biotechnology, Drought Stress and Ecological Fertilization* (Vol. 1, pp. 293–318). Springer, Dordrecht.
14. Cobham, R. O., & Johnson, P. R., (1988). The use of treated sewage effluent for irrigation: Case study from Kuwait. In: Pescod, M. B., & Arar, A., (eds.), *Treatment*, and *Use of Sewage Effluent for Irrigation* (Vol. 1, pp. 1–44). Butterworths, London.
15. Colbach, N., & Debaeke, P., (1998). Integrating crop management and crop rotation effects into models of weed population dynamics: A review. *Weed Science*, *46*(6), 717–728.
16. Conner, A. J., & Jacobs, J. M., (1999). Genetic engineering of crops as potential source of genetic hazard in the human diet. *Mutation Research/Genetic Toxicology and Environmental Mutagenesis*, *443*(1–2), 223–234.
17. Darwish, M. R., El-Awar, F. A., Sharara, M., & Hamdar, B., (1999). Economic-environmental approach for optimum wastewater utilization in irrigation: A case study in Lebanon. *Applied Engineering in Agriculture*, *15*(1), 41.
18. Datta, K. K., & De Jong, C., (2002). Adverse effect of waterlogging and soil salinity on crop and land productivity in north-west region of Haryana, India. *Agricultural Water Management*, *57*(3), 223–238.
19. Dimitriou, I., & Aronsson, P., (2004). Nitrogen leaching from short-rotation willow coppice after intensive irrigation with wastewater. *Biomass and Bioenergy*, *26*(5), 433–441.
20. Dorais, M., (2003). The use of supplemental lighting for vegetable crop production: Light intensity, crop response, nutrition, crop management, cultural practices. In: *Canadian Greenhouse Conference* (Vol. 9, pp. 1–30).
21. Draginčić, J., & Vranešević, M., (2014). AHP-based group decision making approach to supplier selection of irrigation equipment. *Water Resources*, *41*(6), 782–791.
22. Elgallal, M., Fletcher, L., & Evans, B., (2016). Assessment of potential risks associated with chemicals in wastewater used for irrigation in arid and semiarid zones: A review. *Agricultural Water Management*,

177, 419–431.

23. Ensink, J. H., Mahmood, T., & Dalsgaard, A., (2007). Wastewater-irrigated vegetables: market handling versus irrigation water quality. *Tropical Medicine and International Health*, *12*, 2–7.
24. FAO, (1977). Crop water requirements. In: Doorenbos, J., & Pruitt, W., (eds.), *Irrigation, and Drainage* (Vol. 24, pp. 139–144). FAO, Rome.
25. FAO, (1979). Yield response to water. In: Doorenbos, J., & Kassam, A. H., (eds.), *Irrigation, and Drainage* (Vol. 33, pp. 200–203). FAO, Rome.
26. FAO, (1985). Water quality for agriculture. In: Ayers, R. S., & Westcot, D. W., (eds.), *Irrigation, and Drainage FAO* (Vol. 28, pp. 170–174), Rome.
27. FAO, (1988). Irrigation practice and water management. In: Doneen, L. D., & Westcot, D. W., (eds.), *Irrigation and Drainage* (Vol. 1, pp. 66–71), FAO, Rome.
28. Fereres, E., Goldhamer, D. A., & Parsons, L. R., (2003). Irrigation water management of horticultural crops. *HortScience*, *38*(5), 1036–1042.
29. Filip, Z., Kanazawa, S., & Berthelin, J., (1999). Characterization of effects of a long-term wastewater irrigation on soil quality by microbiological and biochemical parameters. *Journal of Plant Nutrition and Soil Science*, *162*(4), 409–413.
30. Follett, R. F., (2001). Soil management concepts and carbon sequestration in cropland soils. *Soil and Tillage Research*, *61*(1–2), 77–92.
31. Gavito, M. E., & Miller, M. H., (1998). Changes in mycorrhiza development in maize induced by crop management practices. *Plant and Soil*, *198*(2), 185–192.
32. Geber, U., (2000). Nutrient removal by grasses irrigated with wastewater and nitrogen balance for reed canary grass. *Journal of Environmental Quality*, *29*(2), 398–406.
33. Gheysari, M., Mirlatifi, S. M., Homaee, M., Asadi, M. E., & Hoogenboom, G., (2009). Nitrate leaching in a silage maize field under different irrigation and nitrogen fertilizer rates. *Agricultural Water Management*, *96*(6), 946–954.
34. Girona, J., Mata, M., Del Campo, J., Arbonés, A., Bartra, E., & Marsal, J., (2006). The use of midday leaf water potential for scheduling deficit irrigation in vineyards. *Irrigation Science*, *24*(2), 115–127.
35. Gordon, W. B., Raney, R. J., & Stone, L. R., (1995). Irrigation

management practices for corn production in north central Kansas. *Journal of Soil and Water Conservation*, *50*(4), 395–399.

36. Grant, O. M., Davies, M. J., Longbottom, H., & Atkinson, C. J., (2009). Irrigation scheduling and irrigation systems: Optimizing irrigation efficiency for container ornamental shrubs. *Irrigation Science*, *27*(2), 139–153.
37. Haque, S. A., (2006). Salinity problems and crop production in coastal regions of Bangladesh. *Pakistan Journal of Botany*, *38*(5), 1359–1365.
38. Heidarpour, M., Mostafazadeh-Fard, B., Koupai, J. A., & Malekian, R., (2007). The effects of treated wastewater on soil chemical properties using subsurface and surface irrigation methods. *Agricultural Water Management*, *90*(1–2), 87–94.
39. Hillel D., (1987). The efficient use of water in irrigation. *World Bank Technical Paper No. 64*, (pp. 1–100). The World Bank, Washington DC.
40. Jabro, J. D., Sainju, U., Stevens, W. B., & Evans, R. G., (2008). Carbon dioxide flux as affected by tillage and irrigation in soil converted from perennial forages to annual crops. *Journal of Environmental Management*, *88*(4), 1478–1484.
41. Jia, Z., Evans, R. O., & Smith, J. T., (2006). Effect of controlled drainage and vegetative buffers on drainage water quality from wastewater irrigated fields. *Journal of Irrigation and Drainage Engineering*, *132*(2), 159–170.
42. Karami, E., (2006). Appropriateness of farmers' adoption of irrigation methods: The application of the AHP model. *Agricultural Systems*, *87*(1), 101–119.
43. Krüger, E., Schmidt, G., & Brückner, U., (1999). Scheduling strawberry irrigation based upon tensiometer measurement and a climatic water balance model. *Scientia Horticulturae*, *81*(4), 409–424.
44. Kumar, D., Heatwole, C. D., Ross, B. B., & Dillaha, T. A., (1992). A knowledge-based system for preliminary selection and economic evaluation of sprinkler irrigation systems. *Applied Engineering in Agriculture*, *8*(4), 441–447.
45. Li, W., & Yang, D. T., (2005). The great leap forward: Anatomy of a central planning disaster. *Journal of Political Economy*, *113*(4), 840–877.
46. Mapanda, F., Mangwayana, E. N., Nyamangara, J., & Giller, K. E., (2005). The effect of long-term irrigation using wastewater on heavy metal contents of soils under vegetables in Harare, Zimbabwe. *Agriculture, Ecosystems and Environment*, *107*(2–3), 151–165.

47. Mizyed, N. R., (2013). Challenges to treated wastewater reuse in arid and semiarid areas. *Environmental Science and Policy*, *25*, 186–195.
48. Mohammad, M. J., & Mazahreh, N., (2003). Changes in soil fertility parameters in response to irrigation of forage crops with secondary treated wastewater. *Communications in Soil Science and Plant Analysis*, *34*(9–10), 1281–1294.
49. Montazar, A., & Behbahani, S. M., (2007). Development of an optimized irrigation system selection model using analytical hierarchy process. *Biosystems Engineering*, *98*(2), 155–165.
50. Murillo, J. M., Lopez, R., Fernandez, J. E., & Cabrera, F., (2000). Olive tree response to irrigation with wastewater from the table olive industry. *Irrigation Science*, *19*(4), 175–180.
51. Murtaza, G., Ghafoor, A., & Qadir, M., (2006). Irrigation and soil management strategies for using saline-sodic water in a cotton-wheat rotation. *Agricultural Water Management*, *81*(1–2), 98–114.
52. Nakayama, F. S., (1982). Water analysis and treatment techniques to control emitter plugging. *Proc. Irrigation Association Conference* (Vol. 1, pp. 1–40), Portland, Oregan.
53. Onder, S., Caliskan, M. E., Onder, D., & Caliskan, S., (2005). Different irrigation methods and water stress effects on potato yield and yield components. *Agricultural Water Management*, *73*(1), 73–86.
54. Oron, G., Armon, R., Mandelbaum, R., Manor, Y., Campos, C., Gillerman, L., & Enriquez, C., (2001). Secondary wastewater disposal for crop irrigation with minimal risks. *Water Science and Technology*, *43*(10), 139–146.
55. Oron, G., Campos, C., Gillerman, L., & Salgot, M., (1999). Wastewater treatment, renovation, and reuse for agricultural irrigation in small communities. *Agricultural Water Management*, *38*(3), 223–234.
56. Oron, G., DeMalach, Y., Hoffman, Z., Keren, Y., Hartman, H., & Plazner, N., (1991). Wastewater disposal by subsurface trickle irrigation. *Water Science and Technology*, *23*(10–12), 2149–2158.
57. Oron, G., Goemans, M., Manor, Y., & Feyen, J., (1995). Poliovirus distribution in the soil-plant system under reuse of secondary wastewater. *Water Research*, *29*(4), 1069–1078.
58. Pandey, S., Giri, K., Kumar, R., Mishra, G., & Rishi, R. R., (2018). Nanopesticides: Opportunities in crop protection and associated environmental risks. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *88*(4), 1287–1308.

59. Papadopoulos, I., & Stylianou, Y., (1988). Ongoing research on the use of treated sewage effluent for irrigating industrial and fodder crops. In: Pescod, M. B., & Arar, A., (eds.), *Treatment, and Use of Sewage Effluent for Irrigation* (Vol. 1, pp. 1–40). Butterworths, Sevenoaks, Kent.
60. Pedrero, F., Kalavrouziotis, I., Alarcón, J. J., Koukoulakis, P., & Asano, T., (2010). Use of treated municipal wastewater in irrigated agriculture: Review of some practices in Spain and Greece. *Agricultural Water Management*, *97*(9), 1233–1241.
61. Pereira, L. S., (1999). Higher performance through combined improvements in irrigation methods and scheduling: A discussion. *Agricultural Water Management*, *40*(2–3), 153–169.
62. Qadir, M., Mateo-Sagasta, J., Jiménez, B., Siebe, C., Siemens, J., & Hanjra, M. A., (2015). Environmental risks and cost-effective risk management in wastewater use systems. In: *Wastewater* (Vol. 1, pp. 55–72). Springer, Dordrecht.
63. Rao, I. M., Zeigler, R. S., Vera, R., & Sarkarung, S., (1993). Selection and breeding for acid-soil tolerance in crops. *BioScience*, *43*(7), 454–465.
64. Rhoades, J. D., Ingvalson, R. D., Tucker, J. M., & Clark, M., (1973). Salts in irrigation drainage waters: I. Effects of irrigation water composition, leaching fraction, and time of year on the salt compositions of irrigation drainage waters. *Soil Science Society of America Journal*, *37*(5), 770–774.
65. Robertson, D., & Wang, Q. J., (2004). Bayesian networks for decision analyses: An application to irrigation system selection. *Australian Journal of Experimental Agriculture*, *44*(2), 145–150.
66. Rusan, M. J. M., Hinnawi, S., & Rousan, L., (2007). Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. *Desalination*, *215*(1–3), 143–152.
67. Saliba, R., Callieris, R., D'Agostino, D., Roma, R., & Scardigno, A., (2018). Stakeholders' attitude towards the reuse of treated wastewater for irrigation in Mediterranean agriculture. *Agricultural Water Management*, *204*, 60–68.
68. Salt, D. E., Blaylock, M., Kumar, N. P., Dushenkov, V., Ensley, B. D., Chet, I., & Raskin, I., (1995). Phytoremediation: A novel strategy for the removal of toxic metals from the environment using plants.

Biotechnology, *13*(5), 468–474.

69. Schmitz, G. H., Schütze, N., & Petersohn, U., (2002). New strategy for optimizing water application under trickle irrigation. *Journal of Irrigation and Drainage Engineering*, *128*(5), 287–297.
70. Scott, C. A., Faruqui, N. I., & Raschid-Sally, L., (2004). Wastewater use in irrigated agriculture: Management challenges in developing countries. *Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities* (Vol. 1, pp. 1–10). CABI Publishing, Wallingford, UK.
71. Snyder, G. H., Augustin, B. J., & Davidson, J. M., (1984). Moisture sensor-controlled irrigation for reducing N leaching in bermuda grass turf 1. *Agronomy Journal*, *76*(6), 964–969.
72. Sojka, R. E., Bjorneberg, D. L., Entry, J. A., Lentz, R. D., & Orts, W. J., (2007). Polyacrylamide in agriculture and environmental land management. *Advances in Agronomy*, *92*, 75–162.
73. Svedman, P., Sandén, G., Arnljots, B., & Banck, G., (1986). A dressing system providing fluid supply and suction drainage used for continuous or intermittent irrigation. *Annals of Plastic Surgery*, *17*(2), 125–133.
74. Thomas, D. L., Harrison, K. A., & Hook, J. E., (2004). Sprinkler irrigation scheduling with the UGA easy pan: performance characteristics. *Applied Engineering In Agriculture*, *20*(4), 439.
75. Velez, J. E., Intrigliolo, D. S., & Castel, J. R., (2007). Scheduling deficit irrigation of citrus trees with maximum daily trunk shrinkage. *Agricultural Water Management*, *90*(3), 197–204.
76. Wang, Z., Chang, A. C., Wu, L., & Crowley, D., (2003). Assessing the soil quality of long-term reclaimed wastewater-irrigated cropland. *Geoderma*, *114*(3–4), 261–278.
77. Zema, D. A., Bombino, G., Andiloro, S., & Zimbone, S. M., (2012). Irrigation of energy crops with urban wastewater: Effects on biomass yields, soils, and heating values. *Agricultural Water Management*, *115*, 55–65.
78. Zhovtonog, O., Dirksen, W., & Roest, K., (2005). Comparative assessment of irrigation sector reforms in Central and Eastern European countries of transition. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *54*(5), 487–500.

5

Agricultural Use of Sewage Sludge

CONTENTS

5.1. INTRODUCTION

A sludge that should be removed is created by many methods of wastewater treatment. Traditional secondary wastewater treatment plants normally produce a primary sludge after the main sedimentation phase of treatment and a secondary sludge after the organic phase of final treatment. Secondary sludge properties are different from the kind of biological operation which is sometimes blended with primary sludge before disposal and treatment. About half of the expenses for operating secondary wastewater treatment plants in Europe may be correlated with the disposal and treatment of sludges. The usage of processed or raw manure sludge by land may minimize considerably the sludge removal cost of sewage treatment and also provide a large amount of the phosphorus and nitrogen to many crops (Kelling et al., 1977a, b; Kirchmann et al., 2017).

Inner-city sewerage systems often carry only household waste to the treatment plants; storm-water and commercial wastewater drainage from highways and other urban areas are also dumped into sewers. Therefore, sewage mud may consist of organic waste products and traces of contaminants used in our modern culture. Some such matters may be phytotoxic and other harmful to livestock and/or humans so the amount of potentially poisonous elements in the soil and their rate of utilization to the soil should be monitored (Soler-Rovira et al., 1995; Jensen and Jepsen, 2005).

Waste sludge often includes pathogenic viruses, protozoa, bacteria, and other parasitic helminths that may become the health risk of animals, plants, and humans. Research by the World Health Organization (1981) on the health hazards of microorganisms in sewage mud added to land described *Taenia* and salmonellae as causing greater concern. Until sludge application to the land, the amount of parasitic and pathogenic microbes in sludge may be greatly decreased by proper sludge treatment and the possible health hazards are more decreased by the impact of climate, soil-microbes, and time. However, restrictions on harvesting, grazing, and planting are appropriate for some crops (Berrow and Webber, 1972; Sauerbeck, 1987).

Besides the concerned elements, waste sludge often includes an important amount of organic, phosphorus, and nitrogen matter. In the year of use, the supply of the phosphorus material is around 50%, which is not based on any previous sludge treatment. The supply of nitrogen is mostly based on the processing of sludge, dry-processed sludge and untreated liquid sludge that gradually releases nitrogen with the long period benefits to crop. Liquid an aerobically digested sludge contains a large concentration of ammonia-nitrogen that is readily accessible to plants and may be especially beneficial for grassland. Some soil structure and water-retaining ability may be enhanced by the organic matter in sludge, particularly when used in the shape of dry sludge block (Directive, 1986) (Figure 5.1).

Figure 5.1: Sewage sludge being sprinkled on agricultural.

Source: https://www.uppermissouriwaterkeeper.org/land-application-of-sewage-sludge-septage/.

The utilization of sewage sludge to the soil in the European Economic Commission (EEC) countries is regulated by Council Directive No. 86/278/EEC (European Communities Council, 1986). Until specified required criteria like the soil and sludge tests, this Directive forbids the usage of sludge from sewage processing plants in agriculture. Following are the parameters to the guideline of the Directive:

1. pH;
2. Organic matter (in percentage dry solids);
3. Dry matter (in percentage);
4. Nickel (milligram/kilogram dry solids);
5. Copper (mg/kg dry solids);
6. Nitrogen, total, and ammoniacal (in percentage dry solids);
7. Zinc (milligram/kilogram dry solids);
8. Phosphorus, total (in percentage dry solids);

93 Lead (milligram/kilogram dry solids);

10. Cadmium (milligram/kilogram dry solids);
11. Chromium (milligram/kilogram dry solids); and
12. Mercury (milligram/kilogram dry solids).

Nowadays the latest Standard of Practice for Industrial Use of Sewage Sludge, the United Kingdom Environment Department (1989) has applied arsenic, selenium, fluoride, and molybdenum to fulfill these parameters. Under the requirements of the Directive, sludge should be examined at least once every 6 months and major improvements in the quality of the processed sewage arise at any period. The analytical frequency for the extra four parameters should be lowered to no less than once every five years, providing that their concentrations in the sludge are continuously no greater than the following concentrations:Se-2 mg/kg dry solids, Mb-3 mg/kg dry solids, Fl-200 mg/kg dry solids and As-2 mg/kg dry solids (Nakada et al., 2006; Li et al., 2008).

5.2. SLUDGE TREATMENT

Even when it is applied into the land, sewage sludge must be subjected to microbial, thermal or chemical treatment, long-term storage or other suitable procedures considered to minimize its ferment-ability and health issues due to its use before applying in agriculture (Suh and Rousseaux, 2002; Yang et al., 2015). Table 5.1 details the methods of sludge management and storage that have been used in the United Kingdom to meet such targets. The second version of a ‘Manual of Good Practice on Soil insertion of Sewage Sludge’ has been developed by the center of Water Research (1989) in the United Kingdom and explains proper procedures and equipment for what is currently the only approach permitted inside the European Economic Commission (EEC) to add unprocessed sludge’s to grassland (Johnson and Sumpter, 2001; Neyens et al., 2004) (Figure 5.2).

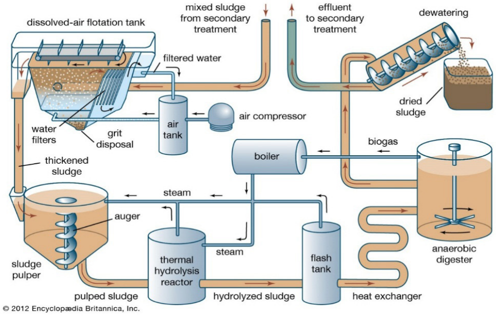


Figure 5.2: Flow chart of a sludge treatment process.

Source: https://www.britannica.com/technology/wastewater-treatment/Sludge-treatment-and-disposal.

Table 5.1: Examples of Effective Sludge Treatment Processes

Process	Descriptions
Mesophilic Anaerobic Digestion	Mean retention period of at least 12 days primary stage in the temperature range of 35°C +/–3°C or of at least 20 days primary stage in the temperature range of 25°C +/–3°C accompanied by a secondary stage which provides a mean retention period of at least 14 days
Sludge Pasteurization	Minimum of 30 minutes at 70°Celcius or a minimum of four hours at 50-five°Celcius (or suitable intermediate conditions), accompanied by primary mesophilic anaerobic digestion throughout both cases
Composting (Windrows or Aerated Piles)	The compost should be maintained at 40°Celcius for at least five days and four hours inside the body of the pile during this period at a minimum of 50-five°Celcius accompanied by a maturation cycle necessary to ensure that the compost reaction is significantly complete
Thermophilic Aerobic Digestion	Mean retention period of at least seven days digestion. All sludge to be subject to a minimum of 50-five°Celcius for at least four hours
Liquid Sludge	that the pH is not less than 12 for a minimum period of two hours. The sludge may then be used directly
Lime Stabilization of	Addition of lime to increase pH to greater than 12 and sufficient to ensure
Dewatering and Storage	Conditioning of unprocessed sludge with lime or other coagulants accompanied by dewatering and preservation of the block for a minimum duration of three months whether the sludge has been subject to primary mesophilic anaerobic digestion, preservation to be for a minimum duration of 14 days
Liquid Storage	preservation of unprocessed liquid sludge for a minimum duration of three months

Source: Department of the Environment (1989); Göbel et al. (2005).

5.3. SLUDGE APPLICATION

As a consequence of sludge usage, amounts of inherently harmful elements in arable soils should not extend certain sensible limitations inside the usual cultivation range. No sludge must be added at any location where the soil composition of each of the criteria meets certain levels, except for molybdenum. Table 5.2 describes estimated allowable amounts of the inherently harmful elements in soil following treatment of waste sludge (according to the United Kingdom policy of Practice). The estimated allowable concentrations for copper, nickel, and zinc differ with the soil pH as it is understood that crop harm from phytotoxic elements mostly occurs on acid soils. This table also specifies the highest allowable annual average rates for the addition of potentially hazardous elements for ten years (Wang, 1997; Zubris and Richards, 2005).

Table 5.2: Maximum Permissible Concentrations of Potentially Toxic Elements in Soil after Application of Sewage Sludge and Maximum Annual Rates of Addition

Potentially Toxic Element (PTE)	**The Maximum Permissible Concentration of PTE in Soil (mg/kg Dry Solids)**				**The Maximum Permissible Average Annual Rate of PTE Addition Over 10 Years (kg/ha)[3]**
	PH[1] 5.0 <5.5	**pH[1] 5.5<6.0**	**pH 6.0–7.0**	**PH[2] > 7.0**	
Copper	80	100	135	200	7.5
Nickel	50	60	75	110	3
Zinc	200	250	300	450	15
Chromium	400 (prov.)	0.1 15 0.15 20 0.7 0.15 0.2			15 (provisional)
Mercury	1				
Lead	300				
Cadmium	3[5]				
*Fluoride	500				
*Arsenic	50				
*Selenium	3				
*Molybdenum[4]	4				

** These parameters are not subject to the requirements of Directive 86/278/EEC.*

[1] The allowable concentrations of copper, zinc, cadmium, and nickel are tentative for soils with a pH in the ranges of 5.0 < 5.5 and 5.5 < 6.0 and would be checked after the current work is done their impact on livestock and certain crops.

[2] The increased allowable Potentially Toxic Element concentrations in soils of pH greater than 7.0 apply only to soils consisting of calcium carbonate greater than 5%.

[3] The yearly rate of utilization of Potentially Toxic Element shall be defined on average for the 10 years ending with the measurement year.

[4] In agricultural fields, the acceptable safe amount of molybdenum is 4 milligram/kilogram. However, there are several places in the United Kingdom where the natural abundance of this element in the soil reaches

this level, for geological purposes. In these situations, there cannot be extra problems by using sludge, however, this should not be repeated only after professional advice. Such recommendations must take into consideration the known amount of soil molybdenum and recent plans to supply copper supplements to livestock.

[5] *For pH 5.0 and above.*

Source: Department of the Environment (1989).

The amounts of possibly harmful elements should be calculated in soil samples collected to a depth of 7.5 cm as sludge is added to the grassland surface (Kladivko and Nelson, 1979; Chang et al., 1984). To reduce livestock injection of fluoride, arsenic, and cadmium applying these contaminants to the soil by sludge application should not reach 3 times the annual average levels over 10 years. The surface sludge added to grassland should not produce lead or fluoride over 1200 and 1000 mg/kg of dry solids, respectively (Hernández et al., 1991; Banerjee et al., 1997; McBride et al., 1997) (Table 5.3).

Table 5.3: Maximum Permissible Concentrations of Potentially Toxic Elements in Soil Under Grass after Application of Sewage Sludge When Samples Taken to a Depth of 7.5 cm

Potentially Toxic Element (PTE)	**The Maximum Permissible Concentration of PTE in Soil (mg/kg dry Solids)**			
	pH 5.0 <5.5	**pH 5.5<6.0**	**pH 6.0<7.0**	**PH > 7.0**
Nickel[1]	80	100	125	180
Copper[2]	130	170	225	330
Zinc[3]	330	420	500	750
Lead	300			
Cadmium[3]	3/5[3]			
Chromium	600 (prov.)			
Mercury	1.5			
*Selenium	5			
*Molybdenum	4			
*Fluoride	500			
*Arsenic	50			

** The requirements of Directive 86/278/EEC do not subject to certain parameters.*

[1] *The allowable concentrations of such elements would be subjected to recheck upon completion of recent research into their impacts on the grassland quality. Before then, in cases where there is uncertainty as to the practicality of plowing or otherwise grassland farming, professional agricultural advice will not apply for sludge which would trigger such concentrations to reach the permissible rates set out in Table 5.3.*

[2] *The allowable cadmium concentration would be subjected to recheck upon completion of current research into its impacts on animals that graze. Before then, this element's concentration can be increased to the permissible upper limit of 5 milligram/kilogram due to sludge utilization only under grass which is maintained in combination with arable crops and grown for conservation purposes only. Any sludge applications shall be rendered in all situations where grazing is allowed which will allow the cadmium content to reach the lower limit of 3 milligram/kilogram.*

[3] For pH 5.0 and above.

Source: Department of the Environment (1989).

5.4. EFFECTS OF SLUDGE ON SOILS AND CROPS

Normally, the normal history of metals concentration in the soil is less obtainable for crop ingestion and thus less harmful than metals added by the application of sewage sludge (Scheltinga, 1987). Research work is performed in the United Kingdom (Carlton-Smith, 1987) found that the amounts of Lead, Zinc, Cadmium, Nickel, and Copper used in liquid sludge at three experimental places might be controlled by the study of the soil profile for 5 years after sludge applications, except for Zinc and Copper applied to calcareous loam soil. Such field tests also found the degree to which metals were transferred from sludge-treated soil to the leaves and edible sections of six crops of major significance to United Kingdom agriculture and the impacts of metals on yields of such crops (Chaney, 1989; Alloway and Jackson, 1991).

While all the plots received enough inorganic fertilizer to satisfy crop nutrient needs, the sludge utilization had some impact on crop yields. In 60% of the cases, analyzed yields of the crop were not substantially impacted but in 26% of the instances, utilization of liquid sludge resulting in slightly higher yields of the crop owing to the positive impact on soil structure. Drop in the yield of wheat grain from 6 to 10% were noted on the sandy loam and clay soils treated with bed-dried sludge and on the clay and calcareous loam soils treated with liquid sludge. Nevertheless, this drop in yield was not believed because of metals, although the most possible cause was the accommodation of the crop due to abundant nitrogen in the soil (Smith, 1994a, b; McGrath et al., 1995).The concentrations of metals increases in the soil because of sludge applications produced important increases in the concentration of Copper, Nickel, Zinc, and Cadmium in the edible section of most of the crops grown: cabbage, wheat, lettuce, red beet, ryegrass, and potato. For certain instances there was no important rise of lead in the tissue of the crop concerning lead in the soil through the application of sludge, indicating that Pb is not generally accessible to crops. The metals supply to crops was determined to be lesser in soil processed with bed dried sludge block compared with liquid sludge; the amount depends on the crop. While the amounts of Copper, Zinc, and Nickel in soils processed with high usage rates of bed-dried and liquid sludge were similar to the total amounts laid down in the EC Guideline and the zinc equivalent of sludge usage reached the limit allowed in the United Kingdom. Directives, with one case, no phytotoxic impacts of metals were noticeable. This was found in kale grown on clay soil as amounts of Zinc and Copper reached higher critical concentrations at elevated sludge usage speeds (MacLean et al., 1987; Hooda and Alloway, 1996).

5.5. PLANTING, GRAZING, AND HARVESTING CONSTRAINTS

To reduce the possible danger to plant, human, and animal health, sludge activities need to be planned in time with processes of harvesting, grazing, or planting. Sludge should not be used in vegetable crops or soft fruit, nor used in crops produced within plastic frameworks or permanent glass (Environment Department, 1989). The EC Directive (Council of the European Communities, 1986) allows a compulsory three weeks no grazing time for processed grassland sludge, however, forbids the dissemination of unprocessed grassland sludge until pumped. Modified sludge may be added without limitation to growing food crops, but it should not be added to growing grass within three months of harvest or to fruit trees during ten months of harvest (Colman and Edwards, 1987; O'Reagain, 1993). If processed sludge is added before growing these crops like cereals, hay, fodder, sugar beet, fruit trees, etc., no limitations exist except in the case of soft fruit and vegetables the processed sludge will not be added within ten months of harvest. Generally, unprocessed sludge ought to be pumped or grown only into the soil before growing crops however may be injected into growing turf or grass, with the limitations on the minimal harvesting time as stated above (Winter and Thompson, 1987; Animut and Goetsch, 2008; Woodward, 2018).

5.6. ENVIRONMENTAL PROTECTION

Always be careful to avoid some sort of unfavorable environmental effects when adding sewage sludge to the soil. Care should also be taken to avoid some sort of adverse environmental effect when adding sewage sludge to the ground. The sludge should not include nondegradable products, for example, plastics, which will cause soil disposal untidy. Moving sludge from the sewage treatment plant to farmland through tanker may generate traffic issues and cause noise and odor disturbance. For their local suitability, automobiles must be carefully chosen, and roads selected to reduce annoyance to the people. Upon consulting with the highway authorities, links to fields should be chosen and extra precautions should be taken to avoid automobiles bringing dirt on the highways (Parr et al., 1978; Wang, 1997).The most critical environmental aspect of adding sludge to land is odor management. Enclosed tankers may be used to transport processed sludge, which is less odorous than unprocessed sludge. Discharge points from tankers or irrigators for sludge must be as close to the soil as feasible and the direction of the liquid sludge must be made small to reduce the visual effect and spray drift. Unprocessed sludge must be pumped under the surface of the soil by injection mounted tankers or using particular trucks (Venkatesan et al., 2004; Rio et al., 2006).Based on weather, topography, and soil factors, considerable caution is required to avoid sludge from flowing off onto roads or adjoining property. On sloping land, there is indeed a danger that these drainages may enter waterways and cause significant contamination of the water. Sludge usage levels ought to be changed appropriately, and distribution may have to be stopped in some situations. Moreover, the issue of surface drainage, contamination can result from the percolation of liquid sludge into land drainage, especially while using injecting techniques or applying liquid sludge to dry fissured soils (Kienholz et al., 1979; Pająk et al., 2013). Sludge must only be used in particularly vulnerable areas with water contamination by the environmental management authority's guidelines as well as through sound agricultural procedures. Sludge storage on fields may improve transportation and application processes, however, every step should be taken to ensure safe storage (Spliethoff et al., 2000).

REFERENCES

1. Alloway, B. J., & Jackson, A. P., (1991). The behavior of heavy metals in sewage sludge-amended soils. *Science of the Total Environment*, *100*, 151–176.
2. Animut, G., & Goetsch, A. L., (2008). Co-grazing of sheep and goats: benefits and constraints. *Small Ruminant Research*, *77*(2–3), 127–145.
3. Banerjee, M. R., Burton, D. L., & Depoe, S., (1997). Impact of sewage sludge application on soil biological characteristics. *Agriculture, Ecosystems and Environment*, *66*(3), 241–249.
4. Berrow, M. L., & Webber, J., (1972). Trace elements in sewage sludge's. *Journal of the Science of Food and Agriculture*, *23*(1), 93–100.
5. Carlton-Smith C. H., (1987). Effects of metals in sludge-treated soils on crops. *Report TR 251*, pp. 1–50. Water Research Centre, Medmenham, UK.
6. Chaney, R. L., (1989). Toxic element accumulation in soils and crops: Protecting soil fertility and agricultural food-chains. In: *Inorganic Contaminants in the Vadose Zone* (Vol. 1, pp. 140–158). Springer, Berlin, Heidelberg.
7. Chang, A. C., Page, A. L., Warneke, J. E., & Grgurevic, E., (1984). Sequential extraction of soil heavy metals following a sludge application. *Journal of Environmental Quality*, *13*(1), 33–38.
8. Colman, J. A., & Edwards, P., (1987). Feeding pathways and environmental constraints in waste-fed aquaculture: balance and optimization. In: *Detritus and Microbial Ecology in Aquaculture. ICLARM Conference Proceedings* (Vol. 14, pp. 240–281).
9. Council of the European Communities, (1986). Council Directive of 12 June 1986 on the protection of the environment, and in particular of soil, when sewage sludge is used in agriculture (86/278/EEC). *Official Journal of the European Communities, L181,* 29 (6), 1–100.
10. Department of the Environment, (1989). *Code of Practice for Agricultural Use of Sewage Sludge* (Vol.1, pp. 1–30). Her Majesty's Stationery Office, London.
11. Directive, C., (1986). Council directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. *Offic. J. Eur. Comm.*, *181*, 6–12.
12. Göbel, A., Thomsen, A., McArdell, C. S., Joss, A., & Giger, W., (2005). Occurrence and sorption behavior of sulfonamides, macrolides, and

trimethoprim in activated sludge treatment. *Environmental Science and Technology*, *39*(11), 3981–3989.

13. Hernández, T., Moreno, J. I., & Costa, F., (1991). Influence of sewage sludge application on crop yields and heavy metal availability. *Soil Science and Plant Nutrition*, *37*(2), 201–210.
14. Hooda, P. S., & Alloway, B. J., (1996). The effect of liming on heavy metal concentrations in wheat, carrots, and spinach grown on previously sludge-applied soils. *The Journal of Agricultural Science*, *127*(3), 289–294.
15. Jensen, J., & Jepsen, S. E., (2005). The production, use, and quality of sewage sludge in Denmark. *Waste Management*, *25*(3), 239–247.
16. Johnson, A. C., & Sumpter, J. P., (2001). Removal of endocrine-disrupting chemicals in activated sludge treatment works. *Environmental Science and Technology*, *35*(24), 4697–4703.
17. Kelling, K. A., Keeney, D. R., Walsh, L. M., & Ryan, J. A., (1977a). A field study of the agricultural use of sewage sludge: III. Effect on uptake and extractability of sludge-borne metals 1. *Journal of Environmental Quality*, *6*(4), 352–358.
18. Kelling, K. A., Walsh, L. M., Keeney, D. R., Ryan, J. A., & Peterson, A. E., (1977b). A field study of the agricultural use of sewage sludge: II. Effect on Soil N and P 1. *Journal of Environmental Quality*, *6*(4), 345–352.
19. Kienholz, E. W., Ward, G. M., Johnson, D. E., Baxter, J., Braude, G., & Stern, G., (1979). Metropolitan Denver sewage sludge fed to feedlot steers. *Journal of Animal Science*, *48*(4), 735–741.
20. Kirchmann, H., Börjesson, G., Kätterer, T., & Cohen, Y., (2017). From agricultural use of sewage sludge to nutrient extraction: A soil science outlook. *Ambio*, *46*(2), 143–154.
21. Kladivko, E. J., & Nelson, D. W., (1979). Changes in soil properties from application of anaerobic sludge. *Journal (Water Pollution Control Federation), 1*, 325–332.
22. Li, H., Jin, Y., Mahar, R., Wang, Z., & Nie, Y., (2008). Effects and model of alkaline waste activated sludge treatment. *Bioresource Technology*, *99*(11), 5140–5144.
23. MacLean, K. S., Robinson, A. R., & MacConnell, H. H., (1987). The effect of sewage-sludge on the heavy metal content of soils and plant tissue. *Communications in Soil Science and Plant Analysis*, *18*(11),

1303–1316.

24. McBride, M. B., Richards, B. K., Steenhuis, T., Russo, J. J., & Sauvé, S., (1997). Mobility and solubility of toxic metals and nutrients in soil 15 years after sludge application. *Soil Science*, *162*(7), 487–500.
25. McGrath, S. P., Chaudri, A. M., & Giller, K. E., (1995). Long-term effects of metals in sewage sludge on soils, microorganisms, and plants. *Journal of Industrial Microbiology*, *14*(2), 94–104.
26. Nakada, N., Tanishima, T., Shinohara, H., Kiri, K., & Takada, H., (2006). Pharmaceutical chemicals and endocrine disrupters in municipal wastewater in Tokyo and their removal during activated sludge treatment. *Water Research*, *40*(17), 3297–3303.
27. Neyens, E., Baeyens, J., & Dewil, R., (2004). Advanced sludge treatment affects extracellular polymeric substances to improve activated sludge dewatering. *Journal of Hazardous Materials*, *106*(2–3), 83–92.
28. O'Reagain, P. J., (1993). Plant structure and the acceptability of different grasses to sheep. *Journal of Range Management*, 1, 232–236.
29. Pająk, T. A. D. E. U. S. Z., (2013). Thermal treatment as sustainable sewage sludge management. *Environment Protection Engineering*, *39*(2), 1–40.
30. Parr, J. F., Epstein, E., & Willson, G. B., (1978). Composting sewage sludge for land application. *Agriculture and Environment*, *4*(2), 123–137.
31. Rio, S., Le Coq, L., Faur, C., Lecomte, D., & Le Cloirec, P., (2006). Preparation of adsorbents from sewage sludge by steam activation for industrial emission treatment. *Process Safety and Environmental Protection*, *84*(4), 258–264.
32. Sauerbeck, D., (1987). Effects of agricultural practices on the physical, chemical, and biological properties of soils: part II—use of sewage sludge and agricultural wastes. In: *Scientific basis for Soil Protection in the European Community* (Vol. 1, pp. 181–210). Springer, Dordrecht.
33. Scheltinga, H. M. H., (1987). Sludge in agriculture: The European approach. *Wat. Sci. Tech., 19*(8), 9–18.
34. Smith, S. R., (1994a). Effect of soil pH on availability to crops of metals in sewage sludge-treated soils. I. Nickel, copper, and zinc uptake and toxicity to ryegrass. *Environmental Pollution*, *85*(3), 321–327.
35. Smith, S. R., (1994b). Effect of soil pH on availability to crops of metals in sewage sludge-treated soils. II. Cadmium uptake by crops

and implications for human dietary intake. *Environmental Pollution*, *86*(1), 5–13.

36. Soler-Rovira, P., Soler-Soler, J., Soler-Rovira, J., & Polo, A., (1995). Agricultural use of sewage sludge and its regulation. *Fertilizer Research*, *43*(1–3), 173–177.
37. Spliethoff, H., Scheurer, W., & Hein, K. R. G., (2000). Effect of co-combustion of sewage sludge and biomass on emissions and heavy metals behavior. *Process Safety and Environmental Protection*, *78*(1), 33–39.
38. Suh, Y. J., & Rousseaux, P., (2002). An LCA of alternative wastewater sludge treatment scenarios. *Resources, Conservation, and Recycling*, *35*(3), 191–200.
39. Venkatesan, A. K., Pycke, B. F., & Halden, R. U., (2014). Detection and occurrence of N-nitrosamines in archived biosolids from the targeted national sewage sludge survey of the US environmental protection agency. *Environmental Science and Technology*, *48*(9), 5085–5092.
40. Wang, M. J., (1997). Land application of sewage sludge in China. *Science of the Total Environment*, *197*(1–3), 149–160.
41. Water Research Centre, (1989). Soil injection of sewage sludge. *A Manual of Good Practice*, (2nd edn., Vol. 2, pp. 1–15). WRC, Medmenham, UK.
42. WHO, (1981). *The Risk to Health of Microbes in Sewage Sludge Applied to Land* (pp. 1–40). EURO Reports and Studies No. 54, Regional Office for Europe, WHO, Copenhagen.
43. Winter, S. R., & Thompson, E. K., (1987). Grazing duration effects on wheat growth and grain yield. *Agronomy Journal*, *79*(1), 110–114.
44. Woodward, S. J., (2018). Dynamical systems models and their application to optimizing grazing management. In: *Agricultural Systems Modeling and Simulation* (Vol. 1, pp. 419–473). CRC Press.
45. Yang, G., Zhang, G., & Wang, H., (2015). Current state of sludge production, management, treatment, and disposal in China. *Water Research*, *78*, 60–73.
46. Zubris, K. A. V., & Richards, B. K., (2005). Synthetic fibers as an indicator of land application of sludge. *Environmental Pollution*, *138*(2), 201–211.

6

Benefits and Drawbacks of Wastewater Use in Agriculture

CONTENTS

6.1. INTRODUCTION

Wastewater recycles in agriculture includes the further utilization of treated wastewater for crop irrigation (Jaramillo and Restrepo, 2017). This kind of reprocessing is considered an effective tool for handling water resources, stemming from the necessity for a controlled supply that compensates for water scarcities caused through seasonality or the irregular obtainability of different water sources for the crop irrigation during the hydrological year (Manga et al., 2001; Jaramillo, 2014). Although the utilization of wastewater is an earlier practice, it has not constantly been appropriately managed or met quality standards as per utilization. Therefore, the knowledge relating to wastewater utilization has progressed with the history of mankind (Angelakis and Snyder, 2015).

Throughout the Bronze Age (3200–1100 BC), ancient civilizations used local wastewater in agriculture to place the water from town settlements. Soil irrigation by wastewater was the most usual practice and has since experienced different growth stages (Angelakis and Gikas, 2014). The first indication of wastewater recycling is found between the ancient Greeks, who used public latrines that blushed wastewater through a sewerage system to a storage chamber. Moreover, Roman and Greek civilizations used local wastewater at the boundaries of major cities (Athens and Rome). Wastewater was transferred to the agricultural arenas to be used as fertilizer for orchards and crops (Cooper, 2005; Tzanakakis et al., 2007).

Amongst the years 1550 to 1700, the direct utilization of wastewater on agricultural areas was stretched to farms in Scotland, England, and Germany. At the start of 1800, soil irrigation by wastewater was implemented in numerous fast-growing cities in the United States and Europe. For instance, the practice was considered lawful in cities like Boston, London, and Paris and was considered a resolution for the disposal and treatment of a large quantity of wastewater (Tzanakakis et al., 2014; Murtaza et al., 2015). Paris was the leading large city to water peri-urban areas by wastewater. It was throughout this similar period that the disposal of metropolitan wastewater was also adopted in Australia. In 1897, the first arena to be irrigated with wastewater was made in Melbourne (Hettiarachchi and Ardakanian, 2016).

In the nineteenth century, the carriage and last disposal of untreated wastewater on open peri-urban arenas caused ruinous epidemics of water-based diseases like as typhoid fever and cholera. Such epidemics encouraged numerous milestones in sanitation like Great Britain’s Public Health Act, founding the “discharge of wastewater on the soil and rainwater in the river” as the basic principle (Karami, 2006). Moreover, the international sanitary measure encouraged by leading European nations led to a chain of sanitary sessions on demography and hygiene. Moreover, the International Office of Public Hygiene was made, to execute sanitary controls beside borders (Metcalf and Eddy Inc et al., 2007; Vilar and Bernabeu-Mestre, 2011). The improvement of underground sewage structures that developed in the mid-19 century is believed to be an additional response to the unhygienic situations causing from the urbanization and heavy industrialization happening at that time. Though, wastewater disposal systems in agricultural fields remain to be widely implemented by the United States and major European cities until the initial twentieth century. Throughout the 1990 s, interest in the utilization of wastewater for agricultural purposes (indirect irrigation by raw wastewater) enhanced in numerous parts of the world because of this sector's large water demands (Asano and Levine, 1996; Jiménez and Asano, 2008).

In this time, wastewater recycle was a worldwide concern because of the allied risks to the environment and public health. Therefore, in 1973, the WHO (World Health Organization) written the document "Reuse of effluents: methods of wastewater treatment and health safeguards," to protect community health and enable the rational utilization of wastewater and excreta in aquaculture and agriculture. This early recommendation was drafted in the lack of epidemiological studies and for a minimal risk methodology (Carr, 2005). In 1986, a comprehensive analysis of all existing epidemiological studies was done, collecting a series of evidence that revealed a need to chapter the rules established in 1973. Established on these considerations, the rules were future updated in 1989 and fresh health indication was incorporated like risk assessments, besides extra information on the description of tolerable risks for community-based on the current situation of a specific disease in a country. In the guidelines, limitations were formed on the microbiological excellence of wastewater for irrigation. Though the WHO (1989) guidelines didn't comprise surveillance guidelines thus, their formulation was planned on the base of objectives and health safety measures. Such considerations were merged as part of the wastewater recommendations made by the WHO in 2006 (Kamizoulis, 2008).

The WHO's 2006 recommendations for the safe utilization of wastewater, gray water, and excreta establish a tool for the protective management of the wastewater in agriculture and make vibrant guidance for the decision-makers on the wastewater application in diverse domestic contexts. The guidelines' primary aim is to assist the formulation of government and standards regulations regarding the utilization and management of wastewater, because of the precise aspects of each country (Mara et al., 2007; Mara and Kramer, 2008). Such guidelines comprised of an important microbiological examination for risk assessment that comprises data collection on pathogens existing in wastewater, irrigated crops, and fields. Besides, the guidelines comprise prevention for wastewater utilization and approximations on health risk management, based on the person per year and disability-adjusted life year (PPY and DALY, respectively).

The FAO (Food and Agriculture Organization) of the United Nations has also formed numerous guidelines relevant to the utilization of wastewater in agriculture. In 1987, the quality of wastewater guidelines for agricultural utilization was published. These guidelines linked the degree of limitation of water utilization to infiltration, toxicity, and salinity parameters of exactions (World Health Organization, 2006; Asante-Annor et al., 2018). In 1999, the FAO printed the proposed guidelines for the "agricultural recycle of treated waters and treatment necessities." In these guidelines, the kind of agricultural recycle was classified on the base of the kind of irrigated crop (Almuktar et al., 2018) (Table 6.1).

Table 6.1: FAO Guidelines for the Agricultural Recycle of Treated Water

Kind of Agricultural Reuse	**Type of Treatment**	**Quality Criterion**
Agricultural recycle in crops that are not consumed.	Secondary-Disinfection	SS < 30 mg/L <200 NMP *E. coli*/100 mL BOD < 30 mg/L pH = 6.5–8.4
Agricultural recycle in crops that are used and not processed commercially.	Secondary-Disinfection	SS < 30 mg/L <200 NMP *E. coli*/100 mL BOD < 30 mg/L pH = 6.5–8.4
Agricultural recycle in crops that are used and not processed commercially.	Secondary Filtration-Disinfection	BOD < 10 mg/L <2 UNT <14 NMP *E. coli*/100 ml <1 Egg/L pH = 6.5–8.4

Source: WHO (2006).

In 1992, the EPA (Environmental Protection Agency) confirmed the poisonous effects on crops revealed to specific trace elements that exist in wastewater used for irrigation. In 2004, the EPA extended the scope of indirect filtered recycle and industrial recycle issues to contain many updated and new case studies, new information on disinfection technologies and treatment, emerging pathogens and chemicals of concern, funding alternatives, and user rates, sources of information and research activities economics, public involvement and acceptance (USEPA, 2004).

In 2012, the USAID (United States Agency for International Development) and EPA reorganized the Guidelines for Wastewater Recycle. The main aim of the update was to enable the development of wastewater to recycle based on a gathering of worldwide experiences. The 2012 guidelines comprised an updated analysis of the provincial difference of water recycle, developments in wastewater treatment expertise, best performs to include communities in planning schemes, international water recycles practices and factors that assist the expansion of sustainable and safe water recycle. More than 300 specialists in the wastewater recycle field collaborated giving technical informs of the guidelines, information on standards, case studies and technical revisions. On the base of quality, the USAID and EPA suggested there be an extremely safe absorption level of trace elements existing in irrigation water. The guidelines of the EPA, FAO, and WHO has been the base for the formulation of the regulations in diverse nations in the world (Griffiths et al., 2012).

Amongst the years 2000 and 2006, more than 3300 wastewater services were registered internationally, within the outline of the AQUAREC international scheme. The several wastewater facilities were categorized by diverse water treatment quality levels and use types, agriculture being the main wastewater user (Amórtegui, 2004). The nations with the greatest number of recycling facilities were the United States and Japan (800 and 1800, respectively), followed by Australia and the E U with 450 and 230, respectively. In the Middle East and Mediterranean regions, around 100 wastewater treatment services were identified, while Latin America was reported to have 50 services, and Sub-Saharan Africa had 20.

The FAO stated that approximately 10% of the total worldwide irrigated land area obtains partially treated or untreated wastewater, including 20 million hectares in 50 nations (Winpenny et al., 2013). Though, Jiménez and Asano (2008) stated that the projected wastewater-irrigated area distinguishes by country and through untreated and treated conditions

(Figure 6.1). Concerning the volume of wastewater used in agriculture, Bixio, and Wintgens (2006) described that the European continent recycles 963 Mm^3/year of raw wastewater. In Latin America, around 400 m^3/s of untreated wastewater is discharged and then used to irrigate different crops (Silva et al., 2008).

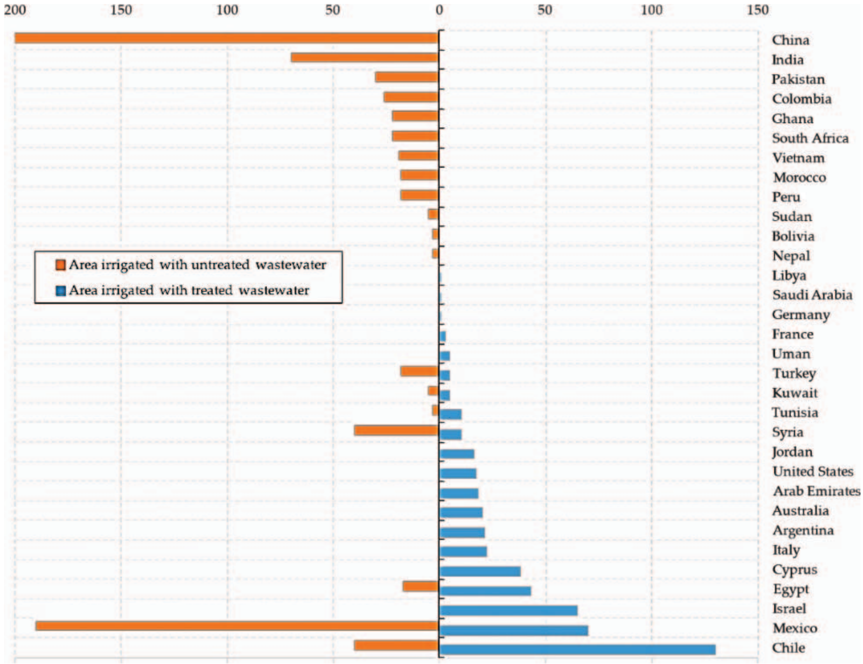


Figure 6.1: Recycle area in agriculture by country.

This chapter describes the effects, both negative and positive of wastewater recycling in agriculture. This practice is significant, particularly in the context of emerging countries challenged with increased water scarcities due to climate change (CC) and variability.

6.2. BENEFITS OF AGRICULTURAL REUSE

The utilization of treated wastewater in agriculture benefits the environment, the economy, and human health. This utilization represents an alternate practice that is being implemented in different regions challenged with water shortages and increasing urban populations with enhancing water needs (WWAP, 2012; Becerra-Castro et al., 2015), particularly given the decrease in groundwater and surface resources caused by climate change

(CC) and climate variability (CV). The obtainability of water resources is also distress by wastewater sourced contamination; as such water is not constantly treated before getting to the surface channels, and through associated aquifer contamination (Foster, 2002; Gomiero et al., 2008).

One of the most renowned benefits of wastewater is utilization in agriculture is the associated decline in pressure on the freshwater sources. Therefore, wastewater serves as an alternative irrigation source, particularly for agriculture, the highest worldwide water user, which consumes 70% of available water. Moreover, wastewater reuse enhances agricultural production in areas experiencing water scarcities, therefore contributing to food protection (Corcoran, 2010). Around 805 million people, 1/9 of the worldwide population, suffer from starvation. Though, according to FAO's recent estimations, a declining trend in starvation supports the possibility of splitting the number of malnourished people. Yet to be successful it is mainly necessary to implement a comprehensive approach that comprises private and public investment aimed at enhancing agricultural yield, in adding to improving and increasing the obtain ability of water resources and guarding vulnerable groups (FAO, 2016).

Depending on the domestic condition, another benefit related to agricultural wastewater recycle could be the evaded cost of taking out groundwater resources.

In this respect, it is worth noticing that the energy need to pump groundwater can signify up to 65% of the costs of irrigation actions (Lal et al., 2013; Saavedra Garcia et al., 2019).

Moreover, the nutrients naturally existing in wastewater permits savings on fertilizer costs to be realized, therefore ensuring a secure and environmentally encouraging nutrient cycle that evades the indirect reoccurrence of microelements and macro (especially phosphorous and nitrogen) to water bodies (Henze and Comeau, 2008; Barreto et al., 2013).

Relying on the nutrients, wastewater might be a potential source of micronutrients (Mg, Fe, Zn, Ca, B, and Mn) and macro (K and P, N) (Jiménez-Cisneros, 1995; Liu and Haynes, 2011). Certainly, wastewater recycle has been proven to increase crop productivity and result in the minimum utilization of fertilizers in agriculture (Oliveira and Von Sperling, 2008; Matheyarasu et al., 2016).

Thus, eutrophication situations in water bodies would be minimized, as would the expenditures for agrochemicals used by farmers (Fatta-Kassinos et al., 2011; Adrover et al., 2012).

The deterrence of water contamination would be another benefit related to wastewater recycling in agriculture. A decline in wastewater discharge assists to improve the source excellence of receiving water bodies (Toze, 2006; Candela et al., 2007). Furthermore, groundwater reservoirs are conserved, as agricultural wastewater recycle renews these sources with greater water quality (Garza-Almanza, 2012).

Moreover, increased utilization of wastewater could contribute to the optimization and installation of treatment facilities to generate effluent of a preferred quality for irrigation objective, representative of an economic advantage to sanitation projects (Gerba and Rose, 2003; Molinos-Senante et al., 2010). In those areas where geographic and climatic characteristics permits, low price wastewater treatment systems may also be a feasible option, achieved using certain technological choices that accomplish the objective of agricultural recycle (Jiménez et al., 2010).

Wastewater uses in agriculture assist to release capital resources by the payment of economic tools through the actors of different nations. An understood economic benefit of agricultural wastewater recycle is the assessment of the treated water discharged for human usage, as this utilization is considered to be of top priority. In some nations, wastewater recycle contributes to decreasing the municipal expense of searching for water sources using more costly means.

On the base of regulatory features, agricultural wastewater recycle can contribute to the explanation of financing mechanisms and appropriate investment policies for pollution prevention and control (Craun et al., 1994).

6.3. HEALTH RISKS OF AGRICULTURAL WASTEWATER REUSE

The kinds of pathogens and concentration levels and chemical substances existing in wastewater differ by region, according to the socioeconomic and sanitary conditions of a specific community (Macedo, 1993; Romero Rojas, 1996).

The concentration of protozoan parasites, helminths, and viruses, in wastewater, can be 10 to 1000 times greater in emerging nations than in developed nations. Table 6.2 presents the primary kinds of enteric pathogens and substances of hygienic interest that can be found in wastewater used for agricultural irrigation.

Table 6.2: Biological Chemical Risks Related to the Utilization of Raw Wastewater in Agriculture

Type of Risk	**Pathogen**	**Effects**
Chemical	The substance of sanitary interest Hydrocarbons Pesticides Heavy Metals	Furans, PCBs Aldrin, Mercury Dioxins, Cadmium, DDT, Arsenic
Biological	Schistosoma Protozoans Helminths Bacteria [1] Virus [2]	*Intestinal Giardia*, *Entamoeba, Cryptosporidium*, spp. *E. coli*, *Shigella* spp, *Salmonella* spp, *Vibrio cholera*, *Tenia* spp., *Ascaris*, *Ancylostoma*, Rotavirus, Norovirus, Hepatitis A and E, Adenovirus, Blood-flukes

[1] *Contact and/or consumption.*

[2] *Consumption.*

Source: WHO (2006).

Wastewater caused diseases can also be acute or chronic. Acute risk resembles the possibility of getting ill in the short period when exposed to small infectious doses of a contaminant, whereas chronic risk states to the presence of contaminants of a chemical nature that impacts human health after a long time of exposure. Furthermore, microbial diseases can be indirectly or directly transferred by water (Table 6.3). Worldwide, such diseases have considerably contributed to early mortality, particularly in developing nations (Saraiva, 2008; Cisneros and Rose, 2009).

Table 6.3: Certain Water-Borne Diseases Associated with Wastewater

Disease	**Cause**
Cholera [2]	*Vibrio cholerae*
Malaria	*Plasmodium*
Leptospirosis [1]	*Leptospira icterohaemorrhagiae*
Giardiasis [1]	*Giardia duodenalis*
Gastroenteritis [2]	Enterovirus, parvovirus, rotavirus

Cryptosporidiosis [1]	*Cryptosporidium*
Amebiasis [2]	*Entamoeba histolytica*
Trachoma	*Chlamydia trachomatis*
Infantile paralysis	Poliovirus
Cyclosporiasis 2	*Cyclospora cayetanensis*
Paratyphoid fever [2]	*Salmonella paratyphi*
Yellow fever	Flavivirus
Gastroenteritis [1]	*Salmonella typhimurium*
Dengue	Flavivirus
Bacillary dysentery [2]	*Shigella dysenteriae*
Ear infections	*Pseudomonas aeruginosa*
Schistosomiasis [2]	*Schistosoma*
Scabies	*Sarcoptes scabiei*
Infectious hepatitis [1]	Hepatitis A
Typhoid fever	*Salmonella typhi*

[1] *Animal and/or human excrement.*

[2] *Human excrement.*

Source: Baquero et al. (2008).

Other compounds that exist in irrigated wastewater that might cause risks to human health are ECs (emerging contaminants). Emerging contaminants are molecules with biological action on diverse organisms, and their physicochemical characteristics define their perseverance in the environment and enable their bioaccumulation. ECs contain antihypertensive, antibiotics, and drugs, analgesics, among others. Also, some ECs correspond to EDs (endocrine disrupters). Such substances of complicated nature were not considered pollutants in the earlier, because of the absence of information on their accumulation in water, air, soil, and animal and vegetal tissue. Though, since the 1990 s, the concentration of the compound initiated to be measured in water sources. Countries like as Germany, Canada, Greece, Italy, Spain, France, and Brazil have projected that loads of analgesics considering around 500 tons have been released into shallow water sources, in which diclofenac and salicylic acid have got concentrations of 3.02 µg/L and 0.22 µg/L, respectively. ECS are frequently introduced into marine media by different anthropogenic sources, which can subsequently result in toxic remains and adverse impacts on marine organisms and, humans.

The wastes of municipal wastewater treatment units are categorized as one of the prime EC sources, as conventional treatment procedures don't efficiently prevent the discharge of these compounds into the environment. Furthermore, farming, and agriculture, as sources of diffuse contamination from antibiotics and pesticides, respectively, are categorized as additional EC sources (Bloom, 2000).

Further sources of superficial water pollution by ECs might occur as a consequence of runoff from soils that comprise animal sludge or excreta digested from wastewater treatment structures used as fertigation or fertilizers. Groundwater pollution by ECs might occur as a consequence of landfill leachate, the leakage from spray irrigation or manure containers with untreated or treated wastewater on farming land.

The impact on human health occurred by ECs is not still fully understood. Though, numerous of these compounds are recognized to change the immunological and endocrine systems of marine organisms. In usual, all compounds that impact the endocrine structure are defined as EDs (endocrine disrupters).

These EDs have been exposed to formed hormonal alterations in some amphibians and fish species (Sparks, 2003); some alterations are related to the secretion of exciting hormones of the TSH (thyroid gland), the LH (luteinizing hormone), and the FSH (follicle-stimulating hormone). Other drugs like carbamazepine, fluoxetine, and clofibrate also amend endocrine activity. Furthermore, ED drugs can't be simply removed in the wastewater treatment facilities. Therefore, EDs get into water sources and superficial waters intended for human usage, therefore chronically revealing human beings to their poisonous effects (Fierer and Jackson, 2006; Brady and Weil, 2008).Pollution through ECs can contribute to the development of resistant microorganisms. The extended utilization of antibiotics in contrast to pathogenic microorganisms in humans and animals and humans, as well as their utilization for food preservation, has enhanced their production and consumption, therefore causing high volume release rates into water bodies with resulting in microbial resistance. Amongst those microorganisms that have shown resistance, some are particularly notable: *Pseudomonas, Salmonella, Aeromonas, Staphylococcus*, *Escherichia*, and *Aeromonas*. Therefore, in the context of legal rules and functionality, the existence of resistant microorganisms in water bodies is a problem of great concern as it associates with wastewater treatment and public health and recycles systems (Powlson et al., 2013).

6.4. LIMITATIONS OF WASTEWATER REUSE IN AGRICULTURE

The utilization of untreated or treated wastewater in agriculture is not discharged from an adverse impact on the environment, particularly on the soil. The scientific literature contains evidence of amendments in the physicochemical parameters of soil. Moreover, in the latest research, fluctuations have been observed in the magnitude and structure of microbial biomass in soil, also an increase in microbial action produced by agricultural wastewater recycle. Changing soil microbiota and physicochemical parameters can affect productivity and fertility, therefore upsetting soil sustainability from insufficient irrigation with wastewater. A chapter follows on the impact of wastewater recycling in agriculture and the effect on physicochemical parameters like as nutrients, contaminants, pH, salinity, organic matter also on microbial diversity. Table 6.4 presents diverse research studies that have been led to the impact of wastewater on soil (Ahmad et al., 2001; Macías, 2004).

Table 6.4: The Influence of Agricultural Recycling on the Soil's Microbiological and Physicochemical Parameters

Parameter	**Associated Impacts on Soil and Environment**	
	Physicochemical Properties	**Microbiological Properties**
Organic matter	· Water retention · Increase in TOC · Increases the availability of contaminants · Formation of aggregates · Enzymatic activity · Improves nutrient content Buffer Capacity · Cation exchange capacity · Soil structure stabilization · Increase in TOC · Increases the availability of contaminants	· Selection of precise soil microhabitats and populations
Contaminants	· Negative impact on soil fertility · Changes in enzyme activity · Soil toxicity and leaching · Decomposition of fallen leaves limiting soil fertility · Mineralization of organic matter · Accumulation in soils · Potential contamination of the food chain	· Enhanced tolerance to microbial pollutants · Antimicrobial resistance · Changes in its structure · Reduction of microbial biomass

Salinity	· Soil sodification or salinization · Increased soil compaction · Decreased stability of aggregates · Changes in soil structure in the long-term · Heavy metal leaching · Negative impact on soil fertility · Variation in soil pH · Decreased stability of aggregates · Dynamics in organic and inorganic compounds · Permeability of soil and water retention	· Changes in variation in the richness and soil microhabitats · Diversity of the microbial community
pH	· Enhances the availability of metals and nutrients · Improves the cation exchange capacity Mineralization of organic matter	· Increases the richness and cation exchange capacity of the microbial community
Nutrients	· Water retention · Improves nutrient content · Increase in organic soil matter · Leaching to groundwater · Risk of eutrophication of aquatic environments	· Perturbation of the metabolic action of microbial soil communities

Source: Jaramillo and Restrepo (2017).

Numerous research studies have stated variations in soil pH causing by irrigation with discharges from municipal wastewater treatment structures at different treatment stages (secondary, primary, and preliminary). Furthermore, alterations in soil pH are associated with three factors: (i) soil texture (ii) period of irrigation; and (iii) type of soil cover. The alterations in soil pH influence the obtainability of metals and nutrients, the CEC (cation exchange capacity), and mineralization of organic matter (Rattan et al., 2005; Lauber et al., 2009; Rousk et al., 2010).

Moreover, different researchers reflect pH incidence to be a significant factor in determining the variety of soil microorganisms and the number of species as an enhancement in free metals is not associated to alterations in the soil pH, and the availability and concentration of metals have the prospective to impact the substrate of the microbial communities (Andrade et al., 2000; Jackson and Sutton, 2008).

Furthermore, organic matter is critical for soil structure and nutrient storage. However, the formation and stabilization of aggregates (clay, lime, and sand), the organic matter constituent contributes to the capability of the soil to retain water, compaction resistance and affecting drainage properties. Organic matter similarly constitutes a deposit of important micronutrient (P, S, and N) and macro for plant development, contributing to the CEC and, resultantly, to soil fertility (Thompson and Troeh, 1988; Sun et al., 2014).

Depending on the quantity of organic matter contributed, diverse studies (Table 6.4) have described enhancement in TOC (total organic carbon) and N (nitrogen) in those soils watered with local wastewater. This phenomenon also results in the obtainability of organic matter to enhance. As a result, the presence of precise bacteria populations may be preferential in the soil. Between 40% and 70% of soil, bacteria are linked with stable aggregates (Zúñiga, 1999; Baquero et al., 2008).

The aggregates stability in the soil and the water retention capability from the organic matter contributed through wastewater irrigation rely on the concentration levels, the composition of soil texture and organic matter. Therefore, sandy clay soils soaked with wastewater enhances the stability of their aggregates (Oke, 1966; Anjana and Iqbal, 2007). On the contrary, soils with a clayey surface reduce the stability of their aggregates. Furthermore, the utilization of wastewater in continued irrigation (more than 20 years) can result in adverse changes in soil structure because of the gathering of sodium in the exchange complex. A study on sugarcane watered with treated wastewater for 1 year found a growth in content of the organic matter in the soil, as per the authors, preferred the recycling of wastewater in the areas under study (Valle del Cauca, Cali, Colombia).

Diverse research studies (Table 6.4) had noted an enhancement in the different types of nitrogen (NH_4-N, N-$NO_{3,}$ or Total N) after irrigation from wastewater for periods extending from 1 to 20 years. Though despite current advantages in agricultural production and a decrease in chemical agents (fertilizers) from the rise in P and N contributed through wastewater, soil microbial groups can be affected, mainly the activities related with the cycle of these elements (Ternes et al., 2001; Avisar et al., 2009).

More than 90% of the soil's nitrogen is in the form of organic. Nitrate and ammonium are the key forms of absorption in plants, in adding to certain organic nitrogen compounds. It is usually believed that nitrite is an intermediary product in the transformation of Ammonium to Nitrate in the soil, where the transformation of Nitrite to Nitrate is significant since relatively little amounts might have poisonous effects on plant growth. These intermediary products of complicated organic substances of nitrogen might be absorbed by plants. Organic nitrogen nourishment can impact the metabolism of the plant and the quality of the plant product. Likewise, under extreme application of nitrogen (by sewage, fertilizer or other sources), vegetables can gather high levels of nitrate and, when used by living things, could pose serious health threats (Biel Maeso, 2011).

An additional effect is the gathering of inorganic N in the soil that might impact the biodegradation of carbon compounds. Furthermore, the extra supply of nutrients in the soil might have adverse effects. Nutrients like nitrate and phosphorus can be comprised in the runoff or can be seeped towards groundwater, therefore causing the toxicity or eutrophication of other habitats (Hutchinson et al., 2006).

Irrigated wastewater can encourage soil sodification (a surplus of interchangeable sodium in relative to other cations) and salinization (an enhancement in the concentration of soluble salts). Salinity problems happen when the soluble salts are intense in the root zone, therefore causing osmotic stress that restricts the capacity of plants to absorb nutrients and water and nutrients (Gozlan et al., 2013).

Sodicity thus negatively affects the soil structure and stability of aggregates, as high substitutable sodium content causes a decrease in permeability. Sodicity is happened by expansive and dispersive procedures on clays as a result of the destruction of aggregates because of high Na^+ concentrations. Diverse research studies noted that variations in sodicity produce an enhancement in soil compaction and decrease the infiltration level of water (Oggier et al., 2010).

As a consequence, soil microbiota is affected by fluctuations in sodicity or soil salinity. The impact on microbial groups is primarily associated with variations in soil structure and reductions in osmotic potential.

Another study evaluated the effects of salinity on the activity, community, and structure of soil microorganisms. Their consequences propose that greater salinity content metabolically pressurize soil microbiota. Moreover, the Carbon Nitrogen relation of the biomass inclines to be lesser in higher salinity soils, which reveals the dominance of bacteria in the microbial biomass of the saline soils (Hirsch et al., 1999).

Moreover, soil degradation enhances due to the disposal of contaminants (pharmaceutical and metals compounds) by different media like wastewater, which gathers in the soil as a consequence of irrigation. Usually, concentrations of metal in soils are not exposed to anthropogenic activities rely mainly on the parental material (stone) and could exist in the soil at nonharmful levels for living beings. Though, industrialization and population growth have resulted in a rise in the occurrence of such contaminating agents in wastewater and, resultantly, in irrigated soils. Metals like Cr, Zn, Ni, Cu, Fe, Cd, and Pb which are plentiful in wastewater, lead the list of probable contaminating agents that have gathered in the soil as a consequence of wastewater irrigation. The existence of these elements in the soil can restrict fertility and/or alter soil microbial groups; they also impact a soil's phytotoxicity potential with effects on pollution and plant growth. Further ecosystem functions affected because of metal pollution comprise litter decomposition, alterations in soil enzyme activity, alterations in microbial structure, organic matter mineralization, and microbial biomass reduction. (Mayor Sanz, 2012).

Furthermore, the metals gathered in the soil can interrelate with pharmaceutical products or other ECs, deteriorating the potential impact on the soil. Numerous studies had also noticed strong co-occurrence patterns among the metals in soil and a confrontation of antibiotics in specific environmental situations. The effect and fate of these compounds (polluting agents and/or emerging metals) depend on numerous factors like as the chemical properties of the contaminant type, the age and species of the vegetation cover, the composition of the rhizosphere microbes and soil characteristics (of the nutritional environment, temperature, soil structure and texture). Certain researchers have noticed that low mobility compounds gather in soils with an irrigation period extending from 1 to 100 years, in comparison with high mobility compounds (Rattan et al., 2005; Li et al., 2013).

Furthermore, researchers globally had highlighted the risks caused by high mobility compounds, given the probable leaching that might contaminate groundwater sources. For instance, in certain amoxicillin-degradation products, it was witnessed that high mobility compounds contaminated the groundwater of wastewater watered agricultural fields. Another study resolved, after discovering of fewer retention rates for ibuprofen in the soils, that this compound has a great potential to infiltrate through the soil and contaminate groundwater sources (Mujeriego, 2005; Grassi et al., 2013).

6.5. ASSESSMENT OF THE RISK-RELATED WITH THE UTILIZATION OF WASTEWATER IN AGRICULTURE

The utilization of wastewater in agriculture has restrictions due to the risks related to the exposed groups, different methods of exposure and concentrations of numerous microbiological and physicochemical parameters. Therefore, soil as a means of getting wastewater, the irrigation technique, the kind of irrigated crop, and the products used, farmers, and their families and end consumers, are exposed during the process chain. By the development of the WHO recommendations of 1989, it was known that human parasites are the key risk to human health and the formation of wastewater treatment structures for the decline in risk was recommended as the key strategy. Therefore, the concept of "zero risks" might only be accomplished under technological patterns of primary, secondary, and disinfection treatment, technically possible but not a practicable solution in the economic and practical context of emerging countries (McArthur and Tuckfield, 2000; Rebollo, 2011).

By the development of the WHO guiding principle of 2006, that required to know the magnitude of the risk related with this kind of practice was formulated and the conceptual basis for its estimation was conveyed, knowing with this that plans for risk decreasing should be flexible and familiar to the local perspective and for the first time suppressed the waste quality thresholds. Therefore, the concept of "multiple barriers" was presented. It suggested a sequence of barriers along the recycle chain, either focusing merely on treatment infrastructure for the development of wastewater quality to be recycled. The WHO (2006) guiding principle raised the health-based objectives, which are assessed from a typical measure of disease nominated about the DALY (Disability Adjusted Life Year). DALY is a quantitative gauge of disease burden, which shows the total amount of healthy life decrease due to disability, or the lifetime that is gone because of premature mortality. The objective designed corresponded to $\leq 10^{-6}$ DALY/person, which is the projected disease burden related to mild diarrhea (Chefetz et al., 2008; Chen et al., 2011).

As per the literature, the risk assessment can be done using 3 kinds of studies: (i) QMRA (quantitative microbiological risk assessment); (ii) microbiological laboratory tests, and (iii) epidemiological studies. Microbiological studies are thought as a source of data for types of studies (i) and (iii) are only suitable if health assessments and suitable protective measures are taken to evade a health risk. Epidemiological studies are a direct measure of the related risk, but their target population and complexity requirements and high costs might limit the method. The QMRA is thought to be an indirect risk measurement that has been extensively used, but its outcomes are related to the precise scenarios evaluated. The combined utilization of the 3 types of studies for the risk estimation might produce better results in their estimation, nevertheless the costs related with each type of study, the time required and the population size, the needed input information, and difficulty of modeling are certain limitations that decide the prioritization of the utilization or the combined utilization of these tools.

QMRA has been considered an important part of risk management. A probabilistic modeling method to evaluate the magnitude of risk under precise scenarios and its implementation is described in 4 steps: (i) hazard detection; (ii) exposure valuation; (iii) dose-response modeling; and (iv) risk classification. The use of this method about wastewater recycling in agriculture has been attentive to the risk assessment in raw customer products, particularly on varieties of lettuce and certain vegetables, and rotavirus infection as the main reason for diarrheal disease in the world (Dalkmann et al., 2012).

In 1992, a chapter of the information gathered in the period from 1975–1989 led to the reformulation of the excellent standards of wastewater of the state of California (United States). Based on the overhead, a proportional study was done of the probable risks of enteric virus infection with tertiary and secondary discharges from treatment systems, as contrasting to four exposure scenarios for wastewater utilization (recreational reservoirs, recharge of aquifers, golf courses and the irrigation of food crops). The investigation of this study revealed that the annual risk of showing a tertiary discharge with chlorine disinfection, with a viral unit content of 100 L, involves an allied risk in golf courses and recreational reservoirs in a range of 10^{-2}–10^{-7}, however in golf courses and crop irrigation, it might have an allied risk between 10^{-6} and 10^{-11}. These are determining outcomes for the prioritization of the investment and the formulation of mitigation plans (Gibson et al., 2010).

Quantitative microbiological risk valuations related to virus in lettuce crops have been the most usually assessed. Scientists assessed the impact of 2 risk factors: (i) the mortality rates for the virus in lettuce farming and (ii) the density function allied with the happening of human enterovirus in irrigation water (Jackson and Sutton, 2008). In an application of the Monte Carlo simulation technique, researchers observed that alterations in density function had a slight change in estimated infection rates. Though, the predicted infection rates were extra delicate than the virus decay rates. A Conclusion Support tool called Recycled water Irrigation Risk Analysis (RIRA) was formed for assessment analysis. This tool assists public health and water managers to conduct QMRA RIRA was formed to simulate an extensive range of situations by describing the pathogen of interest and the exposure situation, using precise dose-response models. The main benefit of RIRA is its flexible and generic structure, which can be used to carry out risk evaluations by the techniques recommended in the main guiding principle on recycled water and local context situations.

Scientists formed a QMRA model to approximate the burden of norovirus disease linked with the usage of irrigated lettuce with raw gray water, a practice usually done in Australia and not permitted by normative guidelines (Kasprzyk-Hordern et al., 2009). The projected yearly disease burden altered over a range of 5×10^{-4} and 2×10^{-8} relying on the source of gray water and how completely the consumer washes the product at the household. The model projected disease loads of 3×10^{-6} and 4×10^{-9} for washing and bath waters respectively. Utilizing these results, the authors suggested the usage of bathwater that fit into normative standards in Australia (threshold value 10^{-6} DALY/person). Besides, in Australia, a QMRA model was formed to see the threat of irrigation with wastewater in other kinds of vegetables like cabbage, cucumber, broccoli, lettuce, and Asian vegetables. Norovirus concentration was used, via fecal dumping rates in black wastewater and the yearly norovirus disease burden later irrigation with treated wastewater (Heberer, 2002). The yearly approximate of disease burden revealed that the primary treatment situations evaluated altered within a range of 10^{-5}–10^{-3} DALY/person, beyond all mean values proposed by the Australian regulations and WHO (threshold $\leq 10^{-6}$ DALY/person). Although, in the advanced treatment situations, most of the cucumber intake situations got mean values of disease burden that accomplish the threshold. In usual, lettuce intake puts the highest risks, however, cucumber intake had the lowest risks. This research was appropriate because it was the 1st QMRA to consider viral gathering by irrigation using wastewater (Cartagena, 2011).

REFERENCES

1. Adrover, M., Farrús, E., Moyà, G., & Vadell, J., (2012). Chemical properties and biological activity in soils of Mallorca following 20 years of treated wastewater irrigation. *Journal of Environmental Management*, *95*, S188–S192.
2. Ahmad, R., Kookana, R. S., Alston, A. M., & Skjemstad, J. O., (2001). The nature of soil organic matter affects sorption of pesticides. 1. Relationships with carbon chemistry as determined by 13C CPMAS NMR spectroscopy. *Environmental Science and Technology*, *35*(5), 878–884.
3. Almuktar, S. A., Abed, S. N., & Scholz, M., (2018). Wetlands for wastewater treatment and subsequent recycling of treated effluent: A review. *Environmental Science and Pollution Research*, *25*(24), 23595–23623.
4. Amórtegui, L. A., (2004). *Wastewater Regeneration and Reuse Systems: Methodology for Technical-Economic Analysis and Cases* (Vol. 1, pp. 1–20). Universitat Politècnica de Catalunya.
5. Andrade, M. L., Marcet, P. Ó. N., Reyzábal, M. L., & Montero, M. J., (2000). Content, evolution of nutrients and productivity in a soil treated with urban waste sludge. *Edaphology*, *7*(3), 21–29.
6. Angelakis, A. N., & Gikas, P., (2014). Water reuse: overview of current practices and trends in the world with emphasis on EU states. *Water Utility Journal*, *8*(67), e78.
7. Angelakis, A. N., & Snyder, S. A., (2015). *Wastewater Treatment and Reuse: Past, Present, and Future, 1,* 1–33.
8. Anjana, S. U., & Iqbal, M., (2007). Nitrate accumulation in plants, factors affecting the process, and human health implications: A review. *Agronomy for Sustainable Development*, *27*(1), 45–57.
9. Asano, T., & Levine, A. D., (1996). Wastewater reclamation, recycling, and reuse: Past, present, and future. *Water Science and Technology*, *33*(10–11), 1.
10. Asante-Annor, A., Bewil, P. N., & Boateng, D., (2018). Evaluation of groundwater suitability for irrigation in the Lambussie-Karni District of Ghana. *Ghana Mining Journal*, *18*(1), 9–19.
11. Avisar, D., Lester, Y., & Ronen, D., (2009). Sulfamethoxazole contamination of a deep phreatic aquifer. *Science of the Total Environment*, *407*(14), 4278–4282.

12. Baquero, F., Martínez, J. L., & Cantón, R., (2008). Antibiotics and antibiotic resistance in water environments. *Current opinion in Biotechnology*, *19*(3), 260–265.
13. Barreto, A. N., Do Nascimento, J. J., Medeiros, E. P. D., Nóbrega, J. A. D., & Bezerra, J. R., (2013). Changes in chemical attributes of a Fluvent cultivated with castor bean and irrigated with wastewater. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *17*(5), 480–486.
14. Becerra-Castro, C., Lopes, A. R., Vaz-Moreira, I., Silva, E. F., Manaia, C. M., & Nunes, O. C., (2015). Wastewater reuse in irrigation: A microbiological perspective on implications in soil fertility and human and environmental health. *Environment International*, *75*, 117–135.
15. Biel, M. M., (2011). *Estimation of Ibuprofen Mobility in Agricultural Soils, 1*, 1–22.
16. Bixio, D., & Wintgens, T., (2006). Water reuse system management. *Manual AQUAREC* (Vol. 1, pp. 1–55). European Commission, Directorate-General for Research, Brussels.
17. Bloom, P. R., (2000). Soil pH and pH buffering. *Handbook of Soil Science*, *1*, B333–B352.
18. Brady, N. C., & Weil, R. R., (2008). The soils around us. *The Nature and Properties of Soils* (14th edn., Vol. 1, pp. 1–31). Pearson Prentice Hall, New Jersey and Ohio.
19. Candela, L., Fabregat, S., Josa, A., Suriol, J., Vigués, N., & Mas, J., (2007). Assessment of soil and groundwater impacts by treated urban wastewater reuse. A case study: Application in a golf course (Girona, Spain). *Science of the Total Environment*, *374*(1), 26–35.
20. Carr, R., (2005). WHO guidelines for safe wastewater use—more than just numbers. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *54*(S1), S103–S111.
21. Cartagena, C. J., (2011). Organic pollutants emerging in the environment: Pharmaceutical products. *Lasallian Research Magazine*, *8* (2), 143–153.
22. Chefetz, B., Mualem, T., & Ben-Ari, J., (2008). Sorption and mobility of pharmaceutical compounds in soil irrigated with reclaimed wastewater. *Chemosphere*, *73*(8), 1335–1343.
23. Chen, F., Ying, G. G., Kong, L. X., Wang, L., Zhao, J. L., Zhou, L. J., & Zhang, L. J., (2011). Distribution and accumulation of endocrine-

disrupting chemicals and pharmaceuticals in wastewater irrigated soils in Hebei, China. *Environmental Pollution*, *159*(6), 1490–1498.

24. Cisneros, B. J., & Rose, J. B., (2009). *Urban Water Security: Managing Risks: UNESCO-IHP* (Vol. 1, pp. 1–44). CRC Press.
25. Cooper, F., (2005). *Colonialism in Question: THEORY, Knowledge, History* (Vol.1, pp. 1–44*)*. University of California Press.
26. Corcoran, E., (2010). *Sick Water? The Central Role of Wastewater Management in Sustainable Development: A Rapid Response Assessment* (Vol. 1, pp. 1–55). UNEP/Earthprint.
27. Craun, G. F., Regli, S., Clark, R. M., Bull, R. J., Doull, J., Grabow, W., & Symons, J. M., (1994). Balancing chemical and microbial risks of drinking water disinfection, Part II. Managing the risks. *Aqua-Journal of Water Supply: Research and Technology*, *43*(5), 207–218.
28. Dalkmann, P., Broszat, M., Siebe, C., Willaschek, E., Sakinc, T., Huebner, J., & Siemens, J., (2012). Correction: Accumulation of pharmaceuticals, *enterococcus*, and resistance genes in soils irrigated with wastewater for zero to 100 years in Central Mexico. *PloS One*, *7*(12), 1–33.
29. FAO, W., (2016). IFAD. *The State of Food Insecurity in the World 2015* (Vol. 1, pp. 1–50). Meeting the 2015 international hunger targets: taking stock of uneven progress. Rome, FAO 2015.
30. Fatta-Kassinos, D., Kalavrouziotis, I. K., Koukoulakis, P. H., & Vasquez, M. I., (2011). The risks associated with wastewater reuse and xenobiotics in the agroecological environment. *Science of the Total Environment*, *409*(19), 3555–3563.
31. Fierer, N., & Jackson, R. B., (2006). The diversity and biogeography of soil bacterial communities. *Proceedings of the National Academy of Sciences*, *103*(3), 626–631.
32. Foster, S., (2002). *Protection of Groundwater Quality: A Guide for Water Companies, Municipal Authorities and Environmental Agencies/ by Stephrn Foster (et al)* (Book No. 629.1 F6, pp. 1–110).
33. Garza-Almanza, V., (2012). *Integrated Wastewater Treatment and Use Systems in Latin America: Reality and Potential, General Study of the Valle de Juárez case, Mexico, 1*, 1–44.
34. Gerba, C. P., & Rose, J. B., (2003). International guidelines for water recycling: Microbiological considerations. *Water Science and Technology: Water Supply*, *3*(4), 311–316.

35. Gibson, R., Durán-Álvarez, J. C., Estrada, K. L., Chávez, A., & Cisneros, B. J., (2010). Accumulation and leaching potential of some pharmaceuticals and potential endocrine disruptors in soils irrigated with wastewater in the Tula Valley, Mexico. *Chemosphere*, *81*(11), 1437–1445.
36. Gomiero, T., Paoletti, M. G., & Pimentel, D., (2008). Energy and environmental issues in organic and conventional agriculture. *Critical Reviews in Plant Sciences*, *27*(4), 239–254.
37. Gozlan, I., Rotstein, A., & Avisar, D., (2013). Amoxicillin-degradation products formed under controlled environmental conditions: Identification and determination in the aquatic environment. *Chemosphere*, *91*(7), 985–992.
38. Grassi, M., Rizzo, L., & Farina, A., (2013). Endocrine disruptors compounds, pharmaceuticals, and personal care products in urban wastewater: Implications for agricultural reuse and their removal by adsorption process. *Environmental Science and Pollution Research*, *20*(6), 3616–3628.
39. Griffiths, C., Klemick, H., Massey, M., Moore, C., Newbold, S., Simpson, D., & Wheeler, W., (2012). US Environmental Protection Agency valuation of surface water quality improvements. *Review of Environmental Economics and Policy*, *6*(1), 130–146.
40. Heberer, T., (2002). Tracking persistent pharmaceutical residues from municipal sewage to drinking water. *Journal of Hydrology*, *266*(3–4), 175–189.
41. Henze, M., & Comeau, Y., (2008). Wastewater characterization. *Biological Wastewater Treatment: Principles Modeling and Design, 1*, 33–52.
42. Hettiarachchi, H., & Ardakanian, R., (2016). *Safe use of Wastewater in Agriculture: Good Practice Examples* (Vol. 1, pp. 1–20). United Nations University, Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES).
43. Hirsch, R., Ternes, T., Haberer, K., & Kratz, K. L., (1999). Occurrence of antibiotics in the aquatic environment. *Sci. Total Environ., 225*, 109–118.
44. Hutchinson, T. H., Ankley, G. T., Segner, H., & Tyler, C. R., (2006). Screening and testing for endocrine disruption in fish—biomarkers as “signposts,” not “traffic lights,” in risk assessment. *Environmental*

Health Perspectives, *114*(1), 106–114.

45. Jackson, J., & Sutton, R., (2008). Sources of endocrine-disrupting chemicals in urban wastewater, Oakland, CA. *Science of the Total Environment*, *405*(1–3), 153–160.
46. Jaramillo, M. F., & Restrepo, I., (2017). Wastewater reuse in agriculture: A review about its limitations and benefits. *Sustainability*, *9*(10), 1734.
47. Jaramillo, M. F., (2014). *Domestic Wastewater Reuse Potential as a Pollution Prevention and Control Strategy in the Cauca River Geographical Valley* (Vol. 1, pp. 1–40). Doctoral dissertation, Master's Thesis, Universidad del Valle, Cali, Colombia.
48. Jiménez, B., & Asano, T., (2008). *Water Reuse: An International Survey of Current Practice, Issues, and Needs* (Vol. 1, pp. 1–33). London: IWA.
49. Jiménez, B., Mara, D., Carr, R., & Brissaud, F., (2010). Wastewater treatment for pathogen removal and nutrient conservation: Suitable systems for use in developing countries. *Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-Income Countries, 1*, 149–169.
50. Jiménez-Cisneros, B., (1995). Wastewater reuse to increase soil productivity. *Water Science and Technology*, *32*(12), 173–180.
51. Kamizoulis, G., (2008). Setting health based targets for water reuse (in agriculture). *Desalination*, *218*(1–3), 154–163.
52. Karami, E., (2006). Appropriateness of farmers' adoption of irrigation methods: The application of the AHP model. *Agricultural Systems*, *87*(1), 101–119.
53. Kasprzyk-Hordern, B., Dinsdale, R. M., & Guwy, A. J., (2009). The removal of pharmaceuticals, personal care products, endocrine disruptors, and illicit drugs during wastewater treatment and its impact on the quality of receiving waters. *Water Research*, *43*(2), 363–380.
54. Lal, K., Yadav, R. K., Kaur, R., Bundela, D. S., Khan, M. I., Chaudhary, M., & Singh, G., (2013). Productivity, essential oil yield, and heavy metal accumulation in lemon grass (*Cymbopogon flexuosus*) under varied wastewater-groundwater irrigation regimes. *Industrial Crops and Products*, *45*, 270–278.
55. Lauber, C. L., Hamady, M., Knight, R., & Fierer, N., (2009). Pyrosequencing-based assessment of soil pH as a predictor of soil bacterial community structure at the continental scale. *Appl. Environ.*

Microbiol., *75*(15), 5111–5120.

56. Li, S. X., Wang, Z. H., & Stewart, B. A., (2013). Responses of crop plants to ammonium and nitrate N. In *Advances in Agronomy* (Vol. 118, pp. 205–397). Academic Press.
57. Liu, Y. Y., & Haynes, R. J., (2011). Origin, nature, and treatment of effluents from dairy and meat processing factories and the effects of their irrigation on the quality of agricultural soils. *Critical Reviews in Environmental Science and Technology*, *41*(17), 1531–1599.
58. Macedo, C. G. D., (1993). Weighting of the risks of microbial and chemical origin in the disinfection of drinking water: The Pan-American perspective. *Bulletin of the Pan American Sanitary Bureau (PASB), 115*(5), 1–100.
59. Macías, F., (2004). Recovery of degraded soils, waste reuse, and carbon sequestration: An integral alternative to improve environmental quality. *Rurais Resources*, *1*, 49–56.
60. Manga, J., Logreira, N., & Serralt, J., (2001). Wastewater reuse: An available water resource. *Engineering and Development*, (9), 12–21.
61. Mara, D. D., Sleigh, P. A., Blumenthal, U. J., & Carr, R. M., (2007). Health risks in wastewater irrigation: comparing estimates from quantitative microbial risk analyses and epidemiological studies. *Journal of Water and Health*, *5*(1), 39–50.
62. Mara, D., & Kramer, A., (2008). The 2006 WHO guidelines for wastewater and grey water use in agriculture: A practical interpretation. In: *Efficient Management of Wastewater* (Vol. 1, pp. 1–17). Springer, Berlin, Heidelberg.
63. Matheyarasu, R., Bolan, N. S., & Naidu, R., (2016). Abattoir wastewater irrigation increases the availability of nutrients and influences on plant growth and development. *Water, Air, and Soil Pollution*, *227*(8), 253.
64. Mayor, S. L., (2012). *Evaluation and Management of the Risk Associated with the Reuse of Wastewater, 1*, 1–22.
65. McArthur, J. V., & Tuckfield, R. C., (2000). Spatial patterns in antibiotic resistance among stream bacteria: Effects of industrial pollution. *Appl. Environ. Microbiol.*, *66*(9), 3722–3726.
66. Metcalf & Eddy, Inc., Asano, T., Burton, F. L., Leverenz, H., Tsuchihashi, R., & Tchobanoglous, G., (2007). *Water Reuse* (Vol. 1, pp. 1–43). McGraw-Hill Professional Publishing.
67. Molinos-Senante, M., Hernández-Sancho, F., & Sala-Garrido, R.,

(2010). Economic feasibility study for wastewater treatment: A cost-benefit analysis. *Science of the Total Environment*, *408*(20), 4396–4402.

68. Mujeriego, R., (2005). Water reuse, regulation, and desalination. *Engineering and Territory*, *72*, 16–25.
69. Murtaza, G., Usman, M., & Ahmad, H. R., (2015). Monitoring and management of wastewater for safer crop production. *Global Journal on Advances Pure and Applied Sciences*, *5, 1–33*.
70. Oggier, D. M., Weisbrod, C. J., Stoller, A. M., Zenker, A. K., & Fent, K., (2010). Effects of diazepam on gene expression and link to physiological effects in different life stages in Zebrafish Danio rerio. *Environmental Science and Technology*, *44*(19), 7685–7691.
71. Oke, O. L., (1966). Nitrite toxicity to plants. *Nature*, *212*(5061), 528–528.
72. Oliveira, S. C., & Von, S. M., (2008). Reliability analysis of wastewater treatment plants. *Water Research*, *42*(4–5), 1182–1194.
73. Powlson, D. S., Smith, P., & Smith, J. U., (2013). *Evaluation of Soil Organic Matter Models: Using Existing Long-Term Datasets* (Vol. 38, pp. 1–100). Springer Science & Business Media.
74. Rattan, R. K., Datta, S. P., Chhonkar, P. K., Suribabu, K., & Singh, A. K., (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops, and groundwater: A case study. *Agriculture, Ecosystems and Environment*, *109*(3–4), 310–322.
75. Rebollo, C. P., (2011). *Estudio De Las Drogas Y Sus Metabolitos Como Contaminantes Ambientales En Agua Y Aire Y Como Indicadores De Consumo Poblacional* (Vol. 1, pp. 1–100; Doctoral dissertation, Universidad de Barcelona).
76. Romero, R. J. A., (1996). *Aquachemistry Colombian School and Engineering, Bogotá: Presence Editorial, 1*, 1–22.
77. Rousk, J., Bååth, E., Brookes, P. C., Lauber, C. L., Lozupone, C., Caporaso, J. G., & Fierer, N., (2010). Soil bacterial and fungal communities across a pH gradient in an arable soil. *The ISME Journal*, *4*(10), 1340–1351.
78. Saavedra, G. L., Munares, G., & Harvey, J., (2019). *Implementation of a Computer Tool for Irrigation Management in the Cultivation of Sugarcane* (Vol. 1, pp. 1–33).
79. Saraiva, C. B., (2008). *Polluting Potential of a Small Dairy: A Case*

Study (Doctoral Dissertation, Master's Dissertation) (Vol. 1, pp. 1–33). Postgraduate Program in Food Science and Technology, Federal University of Viçosa, Viçosa.

80. Silva, J., Torres, P., & Madera, C., (2008). Reuse of domestic wastewater in agriculture: A review. *Colombian Agronomy*, *26* (2), 347–359.
81. Sparks, D. L., (2003). *Environmental Soil Chemistry* (Vol. 1, pp. 1–44). Elsevier.
82. Sun, H., Terhonen, E., Koskinen, K., Paulin, L., Kasanen, R., & Asiegbu, F. O., (2014). Bacterial diversity and community structure along different peat soils in boreal forest. *Applied Soil Ecology*, *74*, 37–45.
83. Ternes, T., Bonerz, M., & Schmidt, T., (2001). Determination of neutral pharmaceuticals in wastewater and rivers by liquid chromatography-electrospray tandem mass spectrometry. *Journal of Chromatography A*, *938*(1–2), 175–185.
84. Thompson, L. M., & Troeh, F. R., (1988). *The Soils and Their Fertility, 1,* 10–44.
85. Toze, S., (2006). Reuse of effluent water—benefits and risks. *Agricultural Water Management*, *80*(1–3), 147–159.
86. Tzanakakis, V. E., Koo-Oshima, S., Haddad, M., Apostolidis, N., Angelakis, A. N., Angelakis, A., & Rose, J., (2014). The history of land application and hydroponic systems for wastewater treatment and reuse. *Evolution of Sanitation and Wastewater Technologies through the Centuries* (Vol. 1, pp. 450–457) IWA Publishing: London, UK.
87. Tzanakakis, V. E., Paranychianaki, N. V., & Angelakis, A. N., (2007). Soil as a wastewater treatment system: Historical development. *Water Science and Technology: Water Supply*, *7*(1), 67–75.
88. United States. Environmental Protection Agency, (USEPA). Office of Wastewater Management. Municipal Support Division, National Risk Management Research Laboratory (US). Technology Transfer, and Support Division. (2004). *Guidelines for Water Reuse* (Vol. 1, pp. 1–44). US Environmental Protection Agency.
89. Vilar, J. L. B., & Bernabeu-Mestre, J., (2011). *Health and the State: The International Health Movement and the Spanish Administration (1851–1945)* (Vol. 1, pp. 1–23). University of Valencia.
90. Winpenny, J., Heinz, I., Koo-Oshima, S., Salgot, M., Collado, J., Hernandez, F., & Torricelli, R., (2013). *Water Reuse in Agriculture:*

Benefits for All. Report on Water Issues FAO, 1, 120–124.

91. World Health Organization, (1989). *Health Guidelines for the use of Wastewater in Agriculture and Aquaculture: Report of a WHO Scientific Group [Meeting Held in Geneva from 18 to 23 November 1987]* (Vol. 1, pp. 1–100). World Health Organization.
92. World Health Organization, (2006). *WHO Guidelines for the Safe use of Wastewater Excreta and Grey Water* (Vol. 1, pp. 1–44). World Health Organization.
93. WWAP, U, (2012). *World Water Assessment Programme: The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk, 1*, 1–33.
94. Zúñiga, F. B., (1999). *Introduction to the Study of Soil Contamination by Heavy Metals* (Vol. 1, pp. 1–33).

7

Wastewater Irrigation in Developing Countries

CONTENTS

7.1. INTRODUCTION

For developing countries, the irrigation serves as an essential factor for obtaining food supplies. 34% of the crops are produced by 17% of the world's total cultivable land (Pescod, 1992; Elgallal et al., 2016). Developing countries cover around 192 million hectares which makes almost three-quarters of irrigated land (United Nations, 2003).

This results in a high dependency on water for the production of food (Figure 7.1). Most of the time, to irrigate the land, wastewater is used and this is due to the excessive water demand which is almost 70% of total usage.

It boosts up productivity as it contains organic matter and nutrients. Another benefit is that it is available throughout the year, so one can sow anytime in the year.

Locally, irrigation through wastewater can be very useful (Martijn and Redwood, 2005; Jaramillo and Restrepo, 2017).

Wastewater can be used in many ways to irrigate the land. It can be used as reclaimed water i.e., treated or it can be used as raw wastewater i.e., nontreated.

This water can be applied to crops in both ways, directly, and indirectly, by indirectly we refer to discharged or diluted water coming from reservoirs, canals, or rivers.

Planned projects involve reusability as a part of their plan while it happens spontaneously in developing countries. Industrialized countries reuse the water so that they can provide protection to water bodies and also to minimize wastewater treatment costs.

These can be performed, only when wastewater treatment exists at high ecological standard and when these standards are attained, the wastewater loses a major portion of nutrients and organic matter.

While in developing countries, reuse of water is spontaneous, it is done to avoid water shortage.

It generally runs with water that is of poor quality, it may include raw wastewater, farmers use this water, not because of its fertilizing properties but because they have no other choice to earn a living (Jiménez and Garduño, 2001; IWMI, 2003).

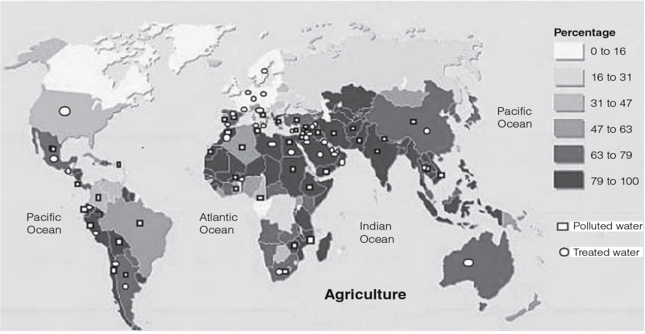


Figure 7.1: Withdrawals of freshwater for agricultural use in 2000 (World Resources Institute, 2000).

Source: https://www.iges.or.jp/en/pub/irrigation-developing-countries-using/en.

In cities, for agricultural irrigation one can use wastewater. Wet countries or urban areas practice this "urban agriculture," it is practiced depending on the availability of wastewater, depending on the people who are spending their lives in extreme poverty having no job opportunities and also on the demand of food products for locals (Shuval, 1990; Jiménez, 2006). For the irrigation of small lands, where fodder, tress, or small products in small quantity can be launched in markets (vegetables and flowers) or for crops that can be used as family diet, open channel flowing wastewater is used (Cockram and Feldman, 1996; Ensink et al., 2004b).

Like every product and activity, wastewater used for irrigation has advantages and disadvantages. Using practical experience and scientific work, the characteristics proposing suitable ways to attain maximum benefit and to reduce the risks are discussed in this paper (Jjumba-Mukasa and Gunders, 1971; Fattal et al., 1998).

7.2. BENEFITS OF APPLYING WASTEWATER FOR IRRIGATION

The benefits wastewater irrigation provides are (Hung and Quy, 2013; Symonds et al., 2014; Astudillo et al., 2015):

1. Higher crop yield is allowed and guaranteed by it, the scope of crops being irrigated can be amplified especially in semiarid and arid areas (Jackson et al., 2003; Bhujel, 2013).

2. The number of nutrients and organic matters are recycled to soils.
3. Fertilizer cost is reduced as it becomes easily available to the farmers who cannot afford fertilizers.
4. Minimizes the usage of synthetic fertilizer.
5. Works as a method for disposal of wastewater at low-cost, under controlled conditions, this method can be hygienic.
6. Pollutants being discharged to surface water bodies are avoided.
7. Increases the investments made in the irrigation sector and also in wastewater disposal, it raises the economic efficiency.
8. Reduces adverse effects on surface water bodies and also conserves sources of freshwater.
9. Capable of recharging aquifers. It is done through infiltration.
10. The expense of pumping wastewater through channels is much less than the expense of pumping groundwater.
11. Marketing and cultivating of valuable crops add great benefit in generating income. This income helps in improving nutrition and helps in providing more education opportunities.

7.3. DRAWBACKS AND RISKS OF USING WASTEWATER FOR AGRICULTURAL IRRIGATION

Wastewater irrigation has the following drawbacks (Chary et al., 2008; Qadir et al., 2010):

1. The reuse of wastewater should be carefully planned to minimize the drawbacks and to get max benefit.
2. Pollution impact is usually less and takes less time in surface water than in soils, because of this reason, governments use delay tactics for the treatment facilities of wastewater.
3. Considering the long-term, it increases metal content in soil and water salinity.
4. We require storage capacity so that the continuously produced wastewater can be adapted with the demand for water by crops and the precipitated water supply.
5. When conditions are not in control, (a) soil productivity may be reduced by the presence of some substances in wastewater; (b) health-related problems for both cattle and human can be caused

by pathogens present in wastewater; (c) aquifer pollution may be caused due to organic matter or pathogens, this aquifer pollution is caused by wastewater infiltration; and (d) wastewater may contain toxic substances for cattle, plant, and even for humans, as they consume crops.

7.4. THE EXTENT OF WASTEWATER USE

There exists no inventory that can be globally used to measure the extent of wastewater being used for irrigation, the reason behind it can be not enough heterogeneous data, and another reason can be that countries fear to disclose their information; if low-quality water is used for irrigation, economic penalties for countries can be imposed on them. Nevertheless, in 50 countries, at least 20 million hectares which make almost 10% of the total irrigated area, are partially treated with wastewater or are irrigated with wastewater (United Nations, 2003) (Figures 7.2 and 7.3).

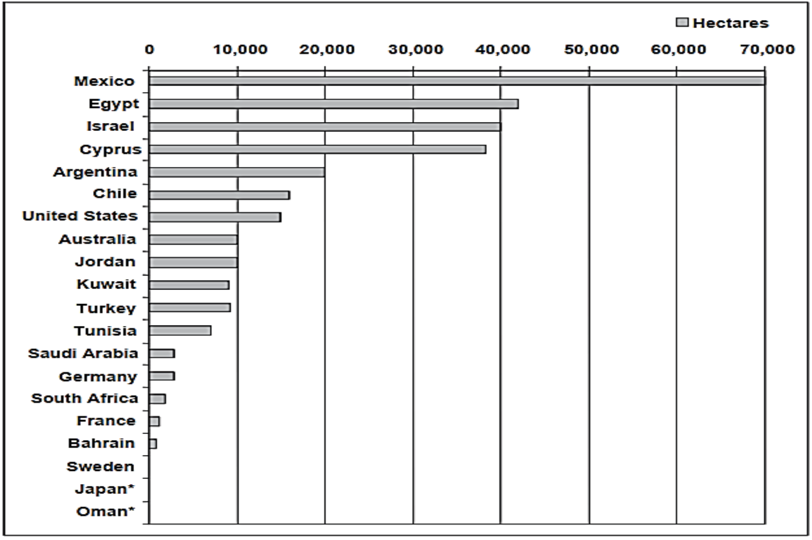


Figure 7.2: The number of hectares (in different countries) irrigated with treated and reclaimed wastewater.

**No data available*

Source: https://www.iges.or.jp/en/pub/irrigation-developing-countries-using/en.

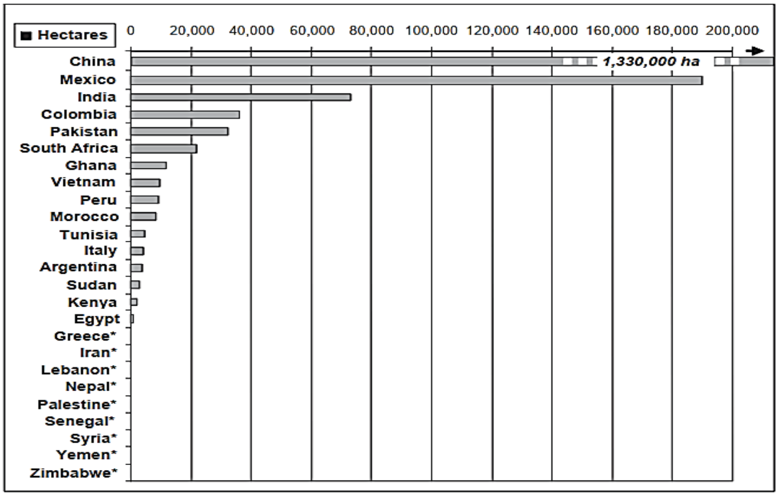


Figure 7.3: Total number of hectares in selected different countries irrigated indirectly and directly with wastewater.

**No data available.*

Source: https://www.iges.or.jp/en/pub/irrigation-developing-countries-using/en.

Almost one-tenth of the population (all around the world) is consuming crops that are irrigated with wastewater (Smit and Nasr, 1992). The use of wastewater varies from region to region. For example, in Hanoi, Vietnam wastewater is used to irrigate around 80% of produced vegetables (Ensink et al., 2004a). The use of wastewater in a region is depending on wastewater treatment, there exist levels to which it is treated (Africa has 0%, the Caribbean and Latin America have 14% and Asia has 35% (WHO and UNICEF, 2000)). There is a high expense for improving sanitation (comparing with other necessary needs), estimates show that countries will continue to use the untreated water for irrigation purposes for an anticipated period. Nonhomogeneous data collected from different countries are shown in Figures 7.2 and 7.3. The figures give us an estimate about hectares irrigated with both, treated and untreated wastewater.

7.5. EFFECTS ON HUMAN HEALTH

Amazingly, wastewater irrigation can affect health in a positive way as well as in a negative way. The positive impact is still being studied, but literature has begun to recognize them, mostly they are food-related problems in poor areas. Producing food through wastewater contributes not only in increasing the income of the poor but also raising the quality of life and increasing nutrition. In under developing countries, 50% of children face death due to malnutrition (yearly around 10.4 million die before reaching their fifth birthday (Rice et al., 2000). In Tanzania, a study revealed that using wastewater for irrigating rice, resulted in more victims of malaria as compared to another nearby village (savannah village), the disease affected less number of people there. There are more resources for a village with a developed irrigation scheme to purchase food, more villagers used and bought mosquito nets, and children experienced a much better nutritional status (Ijumba, 1997).

There are negative impacts of wastewater because it contains toxic chemical compounds and pathogens. There are four groups at great risk: (1) crop handlers; (2) families of agricultural workers and workers themselves too; (3) people (especially children) living in areas where irrigation is done through wastewater; and (4) people who are consuming milk, meat, and crops. Several different excreted organisms are found in wastewater, their concentration and type depend on the level and background of the disease in that particular region. Pathogens (in soil or crop) have the ability to survive for a long period and from there, they are transmitted to animals or humans. Parasitic eggs known as helminth are the most resistant pathogens in the environment. Due to their ability of persistence and resistance, they are considered as a major health risk in using wastewater for irrigation (WHO, 1989), especially in developing countries, as there are around seven to 80 times greater levels in wastewater as compared to the wastewater of other countries (Jiménez, 2003).

Around the world, there is an irregular distribution of disease caused by parasitic worms known as Helminthiases. In developed countries, the population affected by these diseases is less than 1.5% and in developing countries around 25–33% population is affected. In the regions where there are more poverty and bad sanitary conditions, the problem becomes severe affecting 90% of the population (Bratton and Nesse, 1993). Several different types of helminthiasis are observed. in Latin America, the Far East and in Africa commonly observed type is ascariasis. Around 1.3 billion victims of this disease are globally infected. This disease has a low mortality rate, usually, victims have less than 15 years of age and they face problems of impaired fitness and faltering growth. Even if proper treatment is carried out, nearly 1.5 million children will not be able to cope up (Silva et al., 1997).

Other wastewater related diseases are as follows: typhoid, *Helicobacter pylori* causing gastric ulcers, cholera, spoon-shaped nails, giardiasis, and amebiasis (Blumenthal and Peasey, 2002). Using wastewater has gender implications, due to the reason that vegetables (other crops too) require high input from labor, usually, female households increase it. Pathogens can be transferred to others (usually family members), this happens when hygiene standards are not fulfilled especially when working women returns home and carries out cooking like household activities (Van der Hoek et al., 2002).

Talking about wastewater chemical compounds, metal has elementary health concerns. They may be beneficial (biologically speaking) in small amounts but harmful when exposed to high levels. No threshold for human toxicology is developed yet for the intended wastewater irrigation (copper and cobalt) or the defined threshold is high (zinc, fluorine, and boron). Plants do not absorb cobalt, zinc, and copper in significant quantity, so they are not considered here as they are more toxic to plants than to humans so they are not harmful to consumers of plants (Chang et al., 2002). Hexavalent chromium reduces rapidly to trivalent chromium that in soil forms a solid phase which is less soluble. The largest risk is caused by the metal named Cadmium. Depending on the concentration of soil, with time, it can increase its uptake and its lower dose is more toxic to animals and humans, than any other metal that affects the plant. Kidney and liver stores the absorbed cadmium, milk products, and meat remains unaffected (Pescod, 1992).

Cadmium becomes a certain concern when sewage water is mixed with water coming from industries, or industrial water alone is used for irrigation.

Different organic compounds are present in wastewater; some are toxic, cancerous or are responsible for embryo/fetal effects. These effects may vary according to the concentration, type, and duration to which it is exposed. The effects are usually long-term. Endocrine disrupter is an organic compound that is spotted in municipal wastewater. They are derived from several sources, including nonionic detergents, persistent organic pollutants, human pharmaceutical residues, and pesticides. Human health can be affected by these chemicals in a way that they may cause prostate cancer, breast cancer, and testicular cancer, lessen semen quality and quantity, reducing the functionality and causing impaired immune, mental, and working of thyroid in children. There is not enough direct evidence of adverse effects caused on human health but still, in mammals, invertebrates, reptiles, fish, amphibians, and birds observed abnormalities are population disruption, altered immune function, and reproductive abnormalities (WHO, 1999).

Endocrine disrupters and other organic compounds are not studied to a large extent. Generally, it is believed that in soil, by the number of mechanisms, they are reduced, even if they were recalcitrant in water (British Geological Survey, 1998). They can be partially removed if we treat the wastewater. Nonetheless, risks related to health require more attention, especially in under developing countries where industrialization is increasing and there are no proper treatments (disposal too). In developing countries, industrial, and municipal wastewater are not separated. This creates a toxic mixture that is potentially dangerous. Care is necessary to be taken to separate phthalates from aquifers, which were formed by the infiltration of wastewater (Jiménez, 2004; British Geological Survey, 1998).

7.6. EFFECTS ON SOILS

Organic substances and minerals combine to form a complex mixture named soil; its concentration varies according to the climate and region. This variation causes difficulty in deciding the adverse impact of wastewater, or what concentration is beneficial and what concentration causes a problem. The productive increase is classified as the most prominent effect of wastewater irrigation; it is believed that this effect is due to the presence of more organic matter and more nutrients (Mara, 2003; U.S. EPA, 1992). Soil texture is improved by organic matter and effective fertilization is due to the nutrients present in wastewater.

Nitrate, organic nitrogen, nitrites, and ammoniacal nitrogen are the chemical forms in which nitrogen is present. Nitrates are mostly absorbed by the crops directly while all other forms are absorbed by soil and then transformed into crops (National Research Council, 1996). Nitrates are easy water-soluble, as a result, by polluting aquifers or by irrigation, nitrates are drained out of the soil. It is essential to balance the nitrogen amount with the wastewater. This nitrogen amount depends on the demand of crop which is usually 50 to 350 kilograms per hectare, and also on the original concentration of nitrogen in the soil which is usually 0.05–2% (Girovich, 1996). The wastewater contains more nitrogen than the required values that are equal to the rate of irrigation which is 125–875 millimeters (for wastewater), this amount is required for crops but domestic wastewater usually has more than it. Phosphorus has an inverse case. Phosphorus needs to be added always as it is scarce in soil. There is less quantity of phosphorus in wastewater as compared to the quantity needed by crops which is almost

6–12 milligrams per liter. If phosphorus is applied for the long-term, still no negative effect is observed on the environment as it has the potential to be accumulated in soil and also it is very stable (Girovich, 1996). Potassium is another macronutrient in soil and its concentration is quite high. Sewage is capable of supplying the potassium demand which is around 185 kg/ha (Mikkelsen and Camberato, 1995).

Apart from adding nutrients, wastewater irrigation enhances the humic content. Soil humidity is increased by the presence of organic matter, metals are retained, and microbial activity is increased (Ortega-Larrocea et al., 2002). Soil clogging is avoided and as a consequence, productivity of soil increases but only when the content of organic matter is below 350–500 mg/L. Recycling of organic matter, phosphorus, nitrogen, and potassium are essential as their ecological cycles are not interrupted but closed. This closing is performed when compounds detach from wastewater, they are dumped in confinements and trapped in sludge. Considering phosphorus, the process of recycling becomes more essential as it has limited reserves. Even the phosphate industry promotes phosphorus recycling (CEEP, 2001).

Wastewater irrigation does have a negative impact on soils. Increased metal content is one of them. Its harmfulness depends on the level of metal content. Domestic wastewater irrigation results in amassment of metals in the soil's upper layers, even if applied for a long time; there is no adverse effect on crops. Crops, as well as consumers, face damage when industrial wastewater combines with high metal contents. The soil has to achieve a specific level so that crops can uptake the metal and also it should be there in the mobile fraction. In soil, metals are fixed with an increasing amount of organic matter content or with a pH between 6.5–8.5. Luckily, the pH of sewage is slightly alkaline ranging from 7.2–7.6. This value along with other factors is responsible for maintaining original soil pH. Molybdenum, zinc, nickel, copper, and cadmium are the elements of key concern. In soil, heavy metal uptake can be influenced by the absence or presence of divalent metals (Morishita, 1988; Pescod, 1992).

Solids present in wastewater can clog the soil. Clogging depends on the concentration of solid (100–350 mg/L), chemical composition (not biodegraded mineral), and soil porosity. The periodic soil removal by raking and regular drying of soil is required to avoid it.

Groundwater and soil salinization is a major problem caused by reusing water. If proper land drainage and soil washing are not furnished, this condition can occur by freshwater too. So a major concern is that if freshwater can cause it then definitely wastewater reuse will boost up this process. In semiarid and arid regions, salinity effects are the major concerns. In these regions, the salts in the soil are not drained out. The build-up rate of salinization is dependable on the soil transmissivity, land drainage, water quality, irrigation rate, groundwater level depth, and organic matter content. Considering the soil type, drainage, and washing conditions, the problems related to salinity may take place with conductivities might be greater than 3 deciSiemens per meter (dS/m), less than 140 mg/L of chlorine can be dissolved, solids greater than 500 mg/L (if solids which are dissolved are greater than 2,000 mg/L then it can become severe) and the sodium absorption ratio (SAR) is greater than 3–9. The toxic effects produced by bicarbonates, sodium, and boron also contribute to the problems linked to salinity (Armon et al., 2002; Oron et al., 1992; Najafi et al., 2003).

There is an example of Israel, 70% of its municipal effluents are used for agricultural irrigation and as a consequence, Israel is experiencing soil salinization. Preventing the entry of salts in wastewater is less expensive than removing them from wastewater. A program for controlling salt has been adopted which includes regulation in terms of quantity of salts (boron, fluorides, chlorides, and sodium) that are used for regenerating ion exchanger, in detergents and controls saline discharge in sewerage. As an outcome of this, the number of chlorides present in sewage decreased from 120 mg/L to 60 mg/L, in years from 1992 to 2002. The amount of boron also decreased from 0.6 mg/L to 0.3 mg/L, in years from 1999 to 2002 (Weber and Juanicó 2004). This example will be followed by countries using wastewater irrigation techniques (Pahren et al., 1979; Mansell et al., 2004).

7.7. EFFECTS ON CATTLE

Growth and health problems are faced by cattle if they feed on forage that is grown with wastewater. Nonetheless, in areas where water is scarce, mostly in developing countries, cattle are allowed to drink wastewater (Ensink et al., 2004a). If animals survive in irrigated crops, they can get infected by protozoans. Only a little evidence suggests that people consuming the cattle meat grazed on fields irrigated by wastewater or if animals have fed crops from them, the consumers are hardly transmitted by the beef tapeworm (scientific name; *Taenia saginata*). However, strong evidence suggests that Taenia, causing cysticercosis infects the people who consume cattle fed on fields irrigated with raw wastewater or has drunken raw wastewater (Shuval et al., 1985).

Grass tetany can be caused by a high concentration of nitrogen in water used to irrigate fodder. This grass tetany disease is related to an imbalance of potassium, magnesium, and nitrogen in pasture grasses. No problem related to cattle consuming fodder irrigated by wastewater is reported yet. A much lower dose of cadmium may prove to be harmful to animals. The cadmium absorbed stores in the liver and kidney, milk, and meat products remain unaffected. Copper can be harmful to ruminants (not to animals that are mono-gastric but to sheep and cow) at comparatively low concentration than the one that affects plants. In forage consuming animals, negative effects are caused by molybdenum with 10–20 parts per million. For cattle, it is toxic to consume crops with an amount greater than five milligrams of molybdenum per kilogram. Ingestion of sulphate and copper is related to this toxicity.

7.8. EFFECTS ON WATER

Wastewater irrigation improves the quality of the water itself, its effects on water and surface bodies as well.

7.8.1. Wastewater Irrigation

The quality of the wastewater improves when it is used for the same reason for which crops and soils became polluted. In literature, this positive impact has been documented and a treatment process named SAT, soil aquifer treatment is even there (Bouwer, 1987, 1991). Applying it to crops and soils increases salinity but is helpful in reducing microorganisms (100% protozoan and helminths and in between 6–7 log for bacteria), reducing metals by 70–95%, reduces organic matter by almost 90% and reduces different nutrients such as nitrogen by 20–70% and phosphorus by 20–90%.

Absorption and filtration retain microorganisms in the upper soil. The size of the grains (in soil) decreases resulting in efficient removal. The required distance for removing microorganisms increases when they (microorganisms) are small-sized or when soils have coarse-grain materials like macropores, limestone caverns, fractured rocks, and structured or fractured clays (Foster et al., 2004). A relatively higher concentration of magnesium and calcium over potassium and sodium (monovalent cations), more concentration of salts in the sewage, and low pH favors adsorption of microorganisms in the soil.

Organic compounds of animal, humans or plant origin restrained in sewage, rapidly transform to nontoxic and stable organic compounds (in soil) known as fulvic and humic acids. Compared to water bodies, soils are capable of biodegrading a greater number of organic compounds. Applying water in controlled conditions like intermittent flooding and limited irrigation rate, biodegrades hundreds of kilograms of biological oxygen demand per hectare per day (kg BOD/ha/d), without having any effect on the environment (Bouwer, 1991). The level of BOD reduces in the soil after a few meters, TOC; total organic carbon can be still measured in the values of 1–5 mg/L. Removal of endocrine disrupter compounds or organochlorides that are recalcitrant compounds, by biodegradation and adsorption is reported in soils (WHO, 1999; Mansell et al., 2004).

After irrigation, the remaining nitrogen in wastewater depends on the quantity of water that was applied to crops and on the content of nitrogen. If drying periods and flooding periods are alternated, the removal of nitrogen is enhanced; it encourages denitrification/nitrification processes which are capable of removing almost 75% of the nitrogen (Bouwer, 1987).

The phosphorus present in sewage, almost of amount 5–50 mg/L, is changed (biologically) to phosphate. Calcium phosphate is founded by the precipitation of phosphate with calcium at an alkaline pH (also in calcareous soils). Insoluble compounds are formed when phosphate reacts with aluminum oxides and iron present in the soil. Absorption initially immobilizes phosphate in the soil and later on reverts it to the form that is insoluble; this allows more mobile phosphate absorption. Phosphate may act mobile about neutral pH and in clean stands (Bouwer, 1991).

As discussed before, an upper soil layer retains metals. A small amount of metals penetrates the lower layers and a very little amount reaches the crops. For instance, almost 80–94% of nickel, cadmium, zinc, and copper are eliminated in the first 15 cm, lixiviated by runoff is around 5–15% and grass absorbs 1–8% (Pescod, 1992). With boron and fluorine, an almost similar process occurs (Ayres and Wescot, 1985).

Salinization of irrigation water can be better understood by the one when he knows that why more water is applied to remove the salts gathered in the roots due to the evaporation of water, from the soil. This is named as leaching. The water that is used for this leaching process is named as leaching fraction (LF), through agricultural drainage; this water should also be removed. Soil loses its productivity and becomes saline, if this process is not completed properly. In semiarid and arid areas where evaporation is necessary and where there is a high phreatic level, this process is critical. Apart from evaporation, water salinization extent also depends on the hydraulic loading rate and on type of soils too. In sandy soils, evaporation losses compared to the hydraulic loading rate are much less and in the SAT system renovated water, the concentration of salt will be similar to the sewage effluent or it might be slightly higher than it. Increased salinization due to ion exchange and cation absorption will be there if organic matter or clay is in the soil (Pescod, 1992).

7.8.2. Groundwater

Aquifer recharge is a consequence of irrigation; in permeable soil irrespective of the water being used, whether it is reclaimed, reused wastewater or freshwater it occurs (Foster et al., 2004). A recharge takes place usually nonintentionally and it has the benefit of expanding the availability of local water. For irrigation, if excess of water is applied it results in water infiltration. Wastewater recharge for irrigating was used in many areas (Lima's peri-urban area, Jordan; Mezquital Valley, Miraflores, Mexico; Hat Yai, Mexico; Leon, Thailand, and Peru; Wagi Dhuleil) and was analyzed by Foster et al. in 2004, it was estimated that yearly recharged water is 1,000 millimeters at minimum, in most cases this value surpasses the local pluvial precipitation. According to the estimate of Rashed et al. in 1995, infiltration is somewhere equal to 50–70% of the agriculturally used water. Therefore, it should be admitted that the reuse of agricultural water will result in the recharge of aquifer and plans should be made in a better manner.

There are number of factors on which the quality of groundwater depends, these factors include the quality of wastewater used for irrigation, aquifers' vulnerability, irrigation rate, the rate of natural recharge compared to artificial recharge, the way through which irrigation is done, total time for irrigation, different crops type, and the potential use and quality of the underground water (Foster et al., 2004). In literature, the nitrogen impact that usually cited is the risk of developing methemoglobinemia in infants. World Health Organization (WHO) prepared an investigation recently in which it is concluded that in previous time it was accepted that drinking water with more content of nitrates is responsible for causing methemoglobinemia in infants, but now it appears to be in a way that out of many factors, nitrate is also one factor that sometimes plays a part in the development of this disease (Fewtrell, 2004).

Moreover, apparently, there are low cases of methemoglobinemia related to water reported, considering individual behavior and nitrates complex nature, it will be not appropriate to say that the level of nitrate in drinking water is responsible for illness rates. Despite this, evidence proves that aquifers underneath agricultural fields are responsible for the high concentration of nitrates, its existence indicates pollution.

The microorganisms at short distance are removed efficiently by the vadose zone. Nonetheless, some viruses like microorganisms are capable of reaching aquifers but only when their concentration is high (in reused water). In fractured or permeable soil, or where the level of phreatic is high, the wastewater is applied (Foster et al., 2004).

As domestic wastewater carries low levels, generally, metals have a small effect on aquifers. Leach et al. (1980) observed that the metals which are most toxic to humans (lead, mercury, and cadmium) are not found in groundwater at different 5 sites in the US (United States) after the application of primary and secondary effluents for 30–40 years at the rate varying from 0.8 m/yr to 8.6 m/yr, depending on the crops. The reason came forward was that the initial content of metal and soils' pH more than 6.5 was responsible for precipitating metal.

Organic matter reaching out to aquifers by the percolation of reclaimed water lies in between 1–5 mg/L of TOC. For irrigation, if wastewater is used, this content may increase to 6–9 mg/L of TOC. Discussed both ranges are greater than the one accepted safe (not more than 1–2 mg/L of TOC) for human consumption, even for this minor concentration, the type of compound which is causing it will be a concern. If this water is consumed by humans, some of the compounds form organochlorides has to be disinfected with chlorine. Foster et al. (2004) concluded that the, aquifers when recharged with wastewater, their potential of forming trihalomethanes (THM) oscillates, this oscillation somewhere lies in the range of 20 to 45 micrograms per mg of TOC, it can also be capable of producing water (disinfected) with a concentration equal to 100 micrograms per liter. Other industrially originated compounds can be toxic. Fortunately, these kinds of compounds are efficiently absorbed in the soil (Farid et al., 1993).

7.8.3. Surface Water

Running off and irrigation drainage water is received by the surface water bodies which effects them.

Depending on the contact of soil and wastewater, on the use and type of water body (lake, dam, or river), and on the hydraulic retention time, the impact can be observed. If using water for the consumption of humans, bacteria, and viruses are essential concerns as others (helminths ova and protozoan) are already removed by the soil, extreme rain events might be an exception since the transportation of protozoans has been demonstrated (Scott et al., 2004). There are water treatment plants, but they are not capable of treating the high content of microorganism and do not possess the ability to inactivate microbes, as they are not designed accordingly to high content, so microorganism still remains a major concern. A similar thing happens with the organic compounds that are toxic, they affect the quality of surface water bodies as dissolved oxygen is consumed by them; this is not a common thing because, from the soil, most compounds are easily removed. In wastewater, remaining nitrogen causes the major influence to surface water bodies, this nitrogen causes eutrophication of reservoirs, low-speed flowing river, and lakes. Not only water but superior life (fish and birds) is also affected by eutrophication along with recreational loss and consequent biodiversity.

7.9. EFFECTS ON INFRASTRUCTURE

Storage capacity is required for the reconciliation of wastewater production with the demand for water by the crops. To improve the quality of wastewater, dams, and lagoons are built, they deal with it through sedimentation, physical, and biological degradation, desorption, absorption, competition among species, and photolysis. As stated by Juanicó and Milstein (2004), Dams, and lagoons are capable of removing the following: (a) heavy metals; (b) suspended solids; (c) detergents; (d) extent of organic matter relying on time of retention; (e) helminths and majority of bacteria; and (f) organic pollutants (alkylphenols, hydrocarbons, alkylbenzenes, and phthalates). Despite these benefits, for semiarid and arid regions, there exists a drawback of the reservoir that is evaporating water. For example, a pond system near Amman, Jordan named Khirbet As Samra covering an area of 181 hectares undergoes evaporation of around 13–18,000 cubic meters in a single day in summer. The water flow of around 20–25% is accounted for this volume (Duqqah, 2002). As a result of evaporation, by 25% the salt concentration in the effluent (remaining) increases, this increase affects agriculture. Due to unlined nature, lakes, and reservoirs may leak water to the soil. Both these discussed problems can be controlled to a specific extent by using small reservoirs and placing synthetic membranes or compacted clay at the bottom. Affordability of it is dependable on local conditions.

Dams and lagoons like other stagnant water bodies may go through eutrophication because of the nutrient content present in the wastewater. In reservoirs, aquatic plants may act as habitats of diseases like West Nile fever, filariasis, and malaria. In ponds for wastewater stabilization, mosquitoes (*Anopheles* and *Culex*) have been reported in the areas of India, Faisalabad, and Haroonabad (Ensink et al., 2004c).

Combined with a variety of other uses, lagoons, and dams are often used for aquaculture (sometimes when involving wastewater, illegally). Mostly in Asia (countries including Bangladesh, Vietnam, Indonesia, Cameroon, China, Kazakhstan, and Cambodia), for sale or for family consumption, fish production is used. The observed health effects are mostly linked with pathogens (trematodes is a prominent one among all), but metals may give rise to these effects too. Odor problems also arise due to wastewater filled reservoirs.

7.10. EFFECTS ON SOCIOECONOMIC ASPECTS

The reuse of agricultural wastewater may socially be perceived differently in each community. Societies that have not previously reused the wastewater and also the one with high income, oppose the reuse of wastewater due to the number of problems which include odor problems, the effect on health, impact on the environment, as it devalues property, and changes to soil use. In poor areas, the situation is quite different as the people there lack the job opportunities, in these areas; water reuse is the only way of improving the standard of living, as it helps in increasing the income and ensures food supply. In these areas, wastewater serves as an important factor in production, around 50–80% of people income is used on food (Raschid-Sally et al., 2005); therefore, with water quality that is inappropriate and even in small-scaled areas, the agricultural production supports families and complements their diets (Ratta and Nasr, 1996). For all of these reasons, in 15 to 68% of poor cities (in Hanoi, different cities of Africa and India), urban agriculture is practiced (using wastewater). The yearly income of farmers using wastewater irrigation ranges from the lowest of US$155 in Yaoundé, Cameroon, to a maximum of $2,800 in Hyderabad, India (Raschid-Sally et al., 2005). In the El Mezquital Valley, Mexico, utilization of wastewater for irrigation rather than freshwater, raised the land rents from $171 to between $351 and $940 per year, apart from rents, the yield increased too, as wastewater allows to harvest three crops in a year instead of one (Jiménez 2005a). These communities prefer nutrition and food security more than the infectious transmission of diseases (Pescod, 1992; Jiménez and Garduno, 2001; Mara, 2003).

7.11. EFFECTS ON LEGAL MATTERS

The use of wastewater has legal ramifications as well. The utilization of wastewater for agricultural purpose is creating rights, it might not be planned and is also unable to satisfy environmental norms, due to the reason that the customary rights are now entertained everywhere in the world. These rights might conflict with the reuse projects (future planned), particularly when treated wastewater is sold at a greater price than the price that the original user paid. In few countries such as Pakistan, knowing that this product is considered to be unacceptable in other areas of the world, wastewater possesses economic value and its rights are even charged for (Ensink et al., 2004b). In a city of Pakistan, Quetta, $12,000 per year were paid to farmers for wastewater, this price is almost 2.5 times more than that of the freshwater. Concerns related to public health have led to many court cases in different cities of Pakistan (Ensink et al., 2004c). Also in Quetta, following a trial, residents forced the farmers to perform a test for the content of pathogen in their products by a laboratory that is nationally certified. After providing the evidence that their products (crops) were not polluted (though irrigated through wastewater), these farmers were permitted to continue the same practice. Local sanitation agencies and water utilities have filed vast number of cases in Hyderabad. The result of these cases was that the farmers were enforced to abandon the use of wastewater or to pay for it. In a case in Faisalabad, farmers using wastewater appealed against the court decision after proving that they do not have access to any other suitable source of water (Pescod, 1992; FAO and UNESCO, 1973; Foster et al., 2004).

REFERENCES

1. Armon, R., Gold, D., Brodsky, M., & Oron, G., (2002). Surface and subsurface irrigation with effluents of different qualities and presence of cryptosporidium oocysts in soil and on crops. *Water Science and Technology, 46*(3), 115–122.
2. Asano, T., (1998). *Wastewater Reclamation and Reuse*: *Water Quality Management Library* (Vols. 1, 10, pp. 1–29). Lancaster, Technomic Publishing Company.
3. Astudillo, M. F., Thalwitz, G., & Vollrath, F., (2015). Modern analysis of an ancient integrated farming arrangement: Life cycle assessment of a mulberry dyke and pond system. *The International Journal of Life Cycle Assessment*, *20*(10), 1387–1398.
4. Ayres, D., & Westtcott, W., (1985). *Water Quality for Agriculture* (Vol. 1, pp. 1–49). Paper 29. Italy, Food, and Agricultural Organization of the United Nations.
5. Bhujel, R. C., (2013). On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Thailand. *On-farm Feeding and Feed Management in Aquaculture*, *583*, 159–189.
6. Blumenthal, U., & Peasey, A., (2002). *Critical Review of Epidemiological Evidence of the Health Effects of Wastewater and Excreta use in Agriculture* (Vol. 1, pp. 1–55). Geneva, World Health Organization
7. Bouwer, H., (1987). *Soil-aquifer Treatment of Sewage* (Vol. 1, pp. 1–55). Rome, Land, and Water Development Division, Food, and Agriculture Organization of the United Nations (FAO).
8. Bouwer, H., (1991). Groundwater recharge with sewage effluent. *Water Science and Technology, 23*, 2099–2108.
9. Bratton, R., & Nesse, R., (1993). Ascariasis, An infection to watch for in immigrants. *Postgraduate Medicine, 93*, 171–178.
10. British Geological Survey, (BGS), Comision Nacional del Agua (CNA), Sistema de Agua Potable *y* Alcantrillado del Municipio de Lesn (SAPAL), Water Authority of Jordan (WAJ), Department of Mineral Resources (DMR), and Prince of Songkla University (PSU), (1998). *Protecting Groundwater beneath Wastewater Recharge Sites* (Vol. 1, pp. 1–44). BGS technical report WC/98/39. London, British Geological Survey.
11. Centre Européen d'Etudes des Polyphosphates, (CEEP). (2001).

Conference Summary, Second International Conference on Recovery of Phosphates from Sewage and Animal Wastes (Vol. 1, pp. 1–44). At Noordwijkerhout, Netherlands. https://phosphorusplatform.eu/images/download/Noordwijkerhout-conference-summary.pdf.

12. Chang, A., Page, A., & Asano, T., (2002). *Developing Human Health-Related Chemical Guidelines for Reclaimed Wastewater and Sewage Sludge Applications in Agriculture* (Vol. 1, pp. 1–49). Geneva, World Health Organization.
13. Chary, N. S., Kamala, C. T., & Raj, D. S. S., (2008). Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. *Ecotoxicology and Environmental Safety*, *69*(3), 513–524.
14. Cockram, M., & Feldman, S., (1996). The beautiful city gardens in third world cities. *African Urban Quarterly, 11*(2–3), 202–208.
15. Duqqah, M., (2002). Treated sewage water use in irrigated agriculture. Theoretical design of farming systems in Seil Al Zarqa and the Middle Jordan Valley in Jordan. *PhD Thesis* (Vol. 1, pp. 1–59). Wageningen, Wageningen University.
16. Elgallal, M., Fletcher, L., & Evans, B., (2016). Assessment of potential risks associated with chemicals in wastewater used for irrigation in arid and semiarid zones: A review. *Agricultural Water Management*, *177*, 419–431.
17. Ensink, J., Simmons, J., & Van, D. H. W., (2004b). Wastewater use in Pakistan, The cases of Haroonabad and Faisalabad. In: Scott, C., Faruqui, N., & Raschid-Sally, L., (eds.) *Wastewater use in Irrigated Agriculture,* (Vol. 1, pp. 91–102). Wallingford, CAB International.
18. Ensink, J., Mahmood, T., Van, D. H. W., Raschid-Sally, L., & Amerasinghe, F., (2004a). A nationwide assessment of wastewater use in Pakistan, An obscure activity or a vitally important one? *Water Policy, 6*, 197–206.
19. Ensink, J., Van, D. H. W., Matsuno, Y., Munir, S., & Islam, R., (2004c). *Use of Untreated Wastewater in Peri-Urban Agriculture in Pakistan, Risks, and opportunities. Research Report* (Vol. 64, pp. 1–33). Colombo, International Water Management Institute (IWMI).
20. Farid, M., Atta, S., Rashid, M., Munnink, J., & Platenburg, R., (1993). The impact of reuse of domestic wastewater from irrigation on groundwater quality. *Water Science and Technology, 27*(9), 147–157.

21. Fattal, B., Berkovitz, A., & Shuval, H. I., (1998). The efficiency of pilot plant stabilization pond treatment of wastewater. *International Journal of Environmental Health Research*, *8*(2), 153–156.
22. Fewtrell, L., (2004). Drinking-water nitrate and methemoglobinemia. Global burden of disease, a discussion. *Environmental Health Perspectives, 112*(14), 1371–1374.
23. Food and Agricultural Organization of the United Nations, (FAO), and United Nations Educational, Scientific, and Cultural Organization (UNESCO). (1973). *Irrigation, Drainage, and Salinity. An International Sourcebook* (Vol. 1, pp. 1–29). Paris, UNESCO/Hutchinson.
24. Foster, S., Garduño, H., Tuinhof, A., Kemper, K., & Nanni, M., (2004). Urban wastewater as groundwater recharge, Evaluating, and managing the risks and benefits. *Briefing Note* (Vol. 12, pp. 1–44). London, World Bank.
25. Girovich, M., (1996). *Biosolids Treatment and Management, Processes for Beneficial Use* (Vol. 1, pp. 1–44). New York, Marcel Dekker Inc.
26. Hung, L. T., & Quy, O. M., (2013). On-farm feeding and feed management in white leg shrimp (*Litopenaeus vannamei*) farming in Viet Nam. *On-Farm Feeding and Feed Management in Aquaculture*, 337–357.
27. Ijumba, J., (1997). The impact of rice and sugarcane irrigation on malaria transmission in the lower Moshi area of northern Tanzania. *PhD Thesis*. Charlottenlund, Tropical Pesticides Research Institute.
28. International Water Management Institute, (IWMI). (2003). *Confronting the Realities of Wastewater Use in Agriculture* (Vol. 1, pp. 1–19). Water policy briefing 9. Colombo, IWMI.
29. Jackson, C. J., Preston, N., Burford, M. A., & Thompson, P. J., (2003). Managing the development of sustainable shrimp farming in Australia: The role of sedimentation ponds in treatment of farm discharge water. *Aquaculture*, *226*(1–4), 23–34.
30. Jaramillo, M. F., & Restrepo, I., (2017). Wastewater reuse in agriculture: A review about its limitations and benefits. *Sustainability*, *9*(10), 1734.
31. Jiménez, B., (2003). Health risks in aquifer recharge with recycle water. In: Aertgeerts, R., & Angelakis, A., (eds.), *State-of-the-Art Report Health Risk in Aquifer Recharge Using Reclaimed Water* (Vol. 1, pp. 1–22). Rome, WHO Regional Office for Europe.
32. Jiménez, B., (2005a). Treatment technology and standards for

agricultural wastewater reuse a case study in Mexico. *Irrigation and Drainage Journal, 54*(1), 23–35.

33. Jiménez, B., (2005b). Helminths removal for agriculture and aquaculture water reuse. *Proceedings of the 5th International Symposium on Wastewater Reclamation and Reuse for Sustainability* (Vol. 1, pp. 1–33). At Jeju, Korea, International Water Association (IWA).
34. Jiménez, B., (2006). Irrigation in developing countries using wastewater. *International Review for Environmental Strategies*, *6*(2), 229–250.
35. Jiménez, B., & Garduño, H., (2001). Social, political, and scientific dilemmas for massive wastewater reuse in the world. In: Davis, C., & McGin, R., (eds.), *Navigating Rough Waters, Ethical Issues in the Water Industry* (Vol. 1, pp. 1–33). London, American Water Works Association (AWWA).
36. Jjumba-Mukasa, O. R., & Gunders, A. E., (1971). Changing pattern of intestinal helminth infections in Jerusalem. *The American Journal of Tropical Medicine and Hygiene*, *20*(1), 109–116.
37. Juanicó, M., & Milstein, A., (2004). Semi-intensive treatment plants for wastewater reuse in irrigation. *Water Science and Technology, 50*(2), 55–60.
38. Leach, L., Enfield, C., & Harlin, C., (1980). *Summary of long-Term Rapid Infiltration System Studies* (EPA-600/2–80–165, pp. 1–44). Oklahoma, U. S. EPA.
39. Mansell, J., Drewes, J., & Rauch, T., (2004). Removal mechanisms of endocrine disrupting compounds (steroids) during soil aquifer treatment. *Water Science and Technology, 50*(2), 229–237.
40. Mara, D., (2003). *Domestic Wastewater Treatment in Developing Countries.* London, Earth Scan.
41. Martijn, E. J., & Redwood, M., (2005). Wastewater irrigation in developing countries-limitations for farmers to adopt appropriate practices. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *54*(S1), S63–S70.
42. McCornick, P., Hijazi, A., & Sheikh, B., (2004). From wastewater, reuse to water reclamation, progression of water reuse standards in Jordan. In: Scott, C., Faruqui, N., & Raschid, L., (eds.), *Wastewater use in Irrigated Agriculture, Confronting the Livelihood and Environmental Realities* (Vol. 1, pp. 1–29). Wallingford, Commonwealth Agricultural

Bureau International.

43. Mikkelsen, R., & Camberato, J., (1995). Potassium, sulfur, lime, and micronutrient fertilizers In: Rechcigl, J., (ed.), *Soil Amendments and Environmental Quality* (Vol. 1, pp. 1–19). Boca Raton, CRC Press Lewis Publishers.
44. Morishita, T., (1988). Environmental hazards of sewage and industrial effluents on irrigated farmlands in Japan. In: Pescod, M., & Arar, A., (eds.), *Treatment*, and *Use of Sewage Effluent for Irrigation* (Vol. 1, pp. 1–29). London, Food, and Agriculture Organization of the United Nations.
45. Najafi, P., Mousavi, S., & Feizi, M., (2003). Effects of using treated municipal wastewater in irrigation of tomato. *Journal of Agricultural Science and Technology, 15*(1), 65–72.
46. National Research Council, (1996). *Use of Reclaimed Water and Sludge in Food Crop Production* (Vol. 1, pp. 1–39). Washington, DC, National Academy Press.
47. Oron, G., Demalach, Y., Hoffman, Z., & Manor, I., (1992). Effect of effluent quality and application method on agricultural productivity and environmental control. *Water Science and Technology, 26*(7), 1593–1601.
48. Ortega-Larrocea, M., Siebe, C., Bécard, G., Méndez, I., & Webster, R., (2001). Impact of a century of wastewater irrigation on the abundance of arbuscular mycorrhizal (AM) fungi in the Mezquital Valley of Mexico. *Applied Soil Ecology, 16*(2), 149–157.
49. Pahren, H., Lucas, J., Ryan, J., & Dotson, G., (1979). Health risks associated with land application of municipal sludge. *Journal Water Pollution Control Federation, 51*(11), 2588–2601.
50. Pescod, M., (1992). *Wastewater Treatment and Use in Agriculture*: *Paper 47*. Rome, Food, and Agriculture Organization of the United Nations.
51. Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P. G., Drechsel, P., Bahri, A., & Minhas, P. S., (2010). The challenges of wastewater irrigation in developing countries. *Agricultural Water Management*, *97*(4), 561–568.
52. Raschid-Sally, L., Carr, R., & Buechler, S., (2005). Managing wastewater agriculture to improve livelihoods and environmental quality in poor countries. *Journal of Irrigation and Drainage, 54*, 11–

22.

53. Rashed, M., Awad, S., Salam, M., & Smidt, E., (1995). Monitoring of groundwater in Gabal el Asfar wastewater irrigated area (Greater Cairo). *Water Science and Technology, 32*(11), 163–169.
54. Ratta, A., & Nasr, J., (1996). Urban agriculture and the African urban food supply system. *African Urban Quarterly* (1996), *11*(2/3), 154–161.
55. Rice, A., Sacco, L., Hyder, A., & Black, R., (2000). Malnutrition as an underlying cause of childhood deaths associated with infectious diseases in developing countries. *Bulletin of the World Health Organization*, *78*, 1207–1221.
56. Scott, T., Lipp, E., & Rose, J., (2004). The effects of climate change on waterborne disease. In: Cloete, E., Rose, J., Nel, L., & Ford, T., (eds.), *Microbial Waterborne Pathogens*. London, IWA Publishing.
57. Shuval, H. I., (1990). Wastewater irrigation in developing countries: Health effects and technical solutions. *Water and Sanitation Discussion Paper Series UNDP World Bank*, *1*(2), 1–33.
58. Shuval, H., Yekutiel, P., & Fattal, B., (1985). Epidemiological evidence for helminth and cholera transmission by vegetables irrigated with wastewater. Jerusalem-Case study. *Water Science and Technology, 17* (4/5), 433–442.
59. Silva, N., Chan, M., & Bundy, A., (1997). Morbidity and mortality due to ascariasis, Re-estimation, and sensitivity analysis of global numbers at risk. *Tropical Medicine and International Health, 2*(6), 519–528.
60. Smit, J., & Nasr, J., (1992). Urban agriculture for sustainable cities, Using wastes and idle land and water bodies as resources. *Environment and Urbanization, 4*(2), 141–152.
61. Symonds, E. M., Verbyla, M. E., Lukasik, J. O., Kafle, R. C., Breitbart, M., & Mihelcic, J. R., (2014). A case study of enteric virus removal and insights into the associated risk of water reuse for two wastewater treatment pond systems in Bolivia. *Water Research*, *65*, 257–270.
62. United Nations, (2003). *Water for People, Water for Life: The United Nations World Water Development Report* (pp. 1–44). Barcelona, UNESCO.
63. U.S. Environmental Protection Agency (U.S. EPA), (1992). *Guidelines for Water Reuse* (EPA/625/R-92/004). Cincinnati, U.S. EPA.
64. Van, D. H. W., Hassan, M. U., Ensink, J., Feenstra, S., Raschid-Sally,

L., Munir, S., Aslam, R., Ali, N., Hussain, R., & Matsuno, Y., (2002). Urban wastewater, a valuable resource for agriculture. A case study from Haroonabad, Pakistan. *Research Report* (Vol. 63, pp. 1–44). Colombo, International Water Management Institute.

65. Weber, B., & Juanicó, M., (2004). Salt reduction in municipal sewage allocated for reuse: The outcome of a new policy in Israel. *Water Science and Technology, 50*(2), 17–22.
66. World Health Organization, (WHO) and United Nations Children's Fund (UNICEF). (2000). *Global Water Supply and Sanitation Assessment Report* (Vol. 1, pp. 1–40). Geneva, WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation.
67. World Health Organization, (WHO), (1989). *Guidelines for the Safe Use of Wastewater in Agriculture.* Geneva, WHO, (Vol. 1, pp. 1–44).
68. World Health Organization, (WHO). (1999). *The international Programme on Chemical Safety, Endocrine Disruptors* (Vol. 1, pp. 1–44). Geneva, WHO https://www.who.int/ipcs/publications/endocrine_disruptors/en/japan_workshop_report.pdf
69. World Resources Institute (WRI), (2000). *World Resources (2000)–(2001), People, and Ecosystems, the Fraying Web of Life* (Vol. 1, pp. 1–30). Washington, DC, WRI.

8

On-Farm Wastewater Treatment Technologies

CONTENTS

8.1. INTRODUCTION

The shortage of wastewater treatment capability, which is particularly prominent in low-income nations, has caused untreated wastewater contaminating rivers and streams used for crop irrigation. This condition calls for additional options for health threat reduction. Therefore, while cause treatment of wastewater rests the primacy option, applying supplementary, or in the severe case alternative, nontreatment or nonconventional treatment actions seems, at least for the time being, important to minimize health risks stood by the utilization of only partially treated or untreated wastewater in agriculture (Flotats et al., 2009; Hirooka et al., 2009).

This guidance message provides a certain point of using irrigation water treatment choices, which are low cost, frequently form on farmers' own structure and have shown ability in minimizing microbiological crop impurity in smallholder farming (0.050.8 ha) in emerging countries (Mukhtar et al., 2006; Tourre et al., 2008). The efficiency of most systems contrasts with the available area and assurance of farmers to mount and maintain them. Though the area can't be changed, farmers' assurance can be supported by incentives (Riaño and García-González, 2014, 2015).

Farm-based treatment is not ever a particular measure for risk minimization, however, depending on domestic conditions; it might be a significant component of an incremental risk management plan. Its importance comes to appearance in blend with other measures like as postharvest food secure measures and harmless irrigation practices (Ensink et al., 2007). The reader should, therefore, feel encouraged to used the cases shown here as an instance for local upgrading and adaptation. They address filter systems, conventional irrigation structure, and on-farm ponds (Brochero et al., 2005; Keraita et al., 2014).

8.2. POND-BASED ON-FARM WATER TREATMENT SYSTEMS

In numerous countries, smallholder farmers in peri-urban and urban areas use dugouts, ponds, concrete tanks or drums for many reasons (Gingrich et al., 2006; Qadir et al., 2015). Ponds and dugouts might collect subsurface flow or surface flow near streams (Figure 8.1a), work as storage tanks for stream water or pumped drain, or simply minimize walking distances to water bases where watering cans are the sources of irrigation (Figure 8.1b). Where the slope permits, farmers may connect their reservoirs or ponds through narrow trenches in a system which can further decrease manual water carriage (Figure 8.1c). These kinds of casual irrigation infrastructure provide obvious chances for pathogen decrease for example by sedimentation, even at a small scale (Bhujel, 2013; Astudillo et al., 2015).

Pond systems are extensively used as low cost, simple but efficient biological wastewater treatment schemes in numerous countries, not merely in low-income nations. They remove protozoa cysts and helminth eggs mainly through sedimentation, while pathogenic viruses and bacteria are removed through a blend of factors that form an unfavorable environment for their existence. As long as the needed retention times can be, sustained most of these procedures also function in small on-farm ponds (Jackson et al., 2003; Symonds et al., 2014).

To simplify water collection, particularly in smaller wastewater streams or drains, farmers block the flow of water by sandbags or other materials, to form deeper pools appropriate for watering cans. Frequently it is also probable to form cascades of small dams that suggest more choices for sedimentation processes. Table 8.1 shows different types of pond-based systems usually used in developing countries, with the capability to contribute to point of the utilization of wastewater treatment (Keraita et al., 2008, a, 2010; Reymond et al., 2009).

Table 8.1: Summary of Informal Pond Founded Water 'Treatment' Structures in Smallholder Agriculture

	On-Farm Sedimentation Ponds	**"Chinese"-3-Tank System**	**In-Stream Dams**
Description	Previously installed dugouts, small ponds, tanks or, drums (2–10 m^2 surface) used for interim wastewater storing. Generally, water is got from these reservoirs with watering cans however they are full by small pumps.	To improve a one pond system for uninterrupted retention time, 3 ponds are the desired option: 1st pond is being filled through the farmer, 2nd is settling and the settled water from the 3rd is being used for irrigation. The pond size should surpass the daily water requirements.	To ease water gathering in wastewater streams and drains farmers block the flow of water to form pools by sandbags or other materials. These constructions can make cascades appropriate for trapping helminth eggs.

Size of ponds and Area requirement	Differs with crop water requirements (i.e., climate, and crop type) and the size of the cropped farm range		Varies broadly but usually among 1 and 3 m^3
	In West Africa: Pond volumes differ in general among 2 and 10 m^3.	See left	
Pathogen removal	Studies in Ghana demonstrate that a 2 day period of settling eliminates nearly all helminth eggs from the water (decrease to less than 1 egg per liter) and around 2 log units for coli form bacteria. Though, ponds are often used every day or every next day causing lower declines, especially when their volume is small.	A 1 day period of quiescent settling eliminates nearly all helminth eggs and can accomplish a 1 to 2 log unit decrease of other pathogens. The lengthier the water can 'rest' the better.	With more than 1 obstacle helminth egg sedimentation can be important. Fecal coli form decrease of 2 log units was got in Accra. If sandbags are closely packed and perforated, they can also work as sand filters.
Challenges	Touching the lowermost with the watering or Stepping into ponds can mix up settled pathogens (training needed). Having alternate ponds will enhance retention time (see right). Avoiding polluted water/soil or runoff of manure into ponds.	Labor to dig additional ponds than generally used. Pumps suitable to fill ponds from the streams. View comments for ponds left.	Sandbags might be eroded away in the rainy season. Two or more obstacle systems are chosen.

Source: Mara et al. (1996); IWMI (2008a, b).

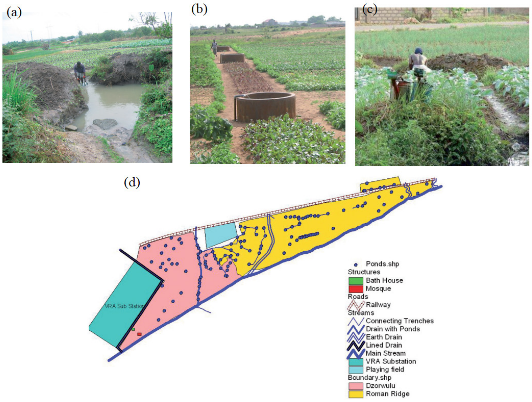


Figure 8.1: (a) Trench on a vegetable farming spot in Kumasi, Ghana, near to a highly contaminated stream (b) Interrelated tank system in Lomé, Togo

(the water base here is shallow groundwater) (c) Distribution of interconnected and individual ponds and trenches on a farming spot in Accra, Ghana, drawing water through pumps from wastewater drains and polluted streams (d) infrastructure map.

Source: https://www.who.int/water_sanitation_health/wastewater/FLASH_OMS_WSHH_Guidance_note4_20100729_17092010.pdf.

8.3. PONDS AS POSSIBLE BREEDING SITES FOR MOSQUITO VECTORS

Ponds built systems are probable habitats of the mosquito vectors of diseases such as filariasis, malaria, and different kinds of a snail or encephalitis intermediary hosts of schistosomiasis (Jaffrin et al., 2004; Hatt et al., 2008).

Opposing to the conventional understanding that anopheline vectors of malaria merely breed in relatively clean water there are progressively indications for example from Nigeria, Ghana,

Tanzania, and Pakistan that certain anopheline species too breed in contaminated water sources (Mukhtar et al., 2003; Sattler et al., 2005).

The actual occurrence though can differ from region to region, kinds of wastewater and among seasons (raw or diluted); thus, extension officers or program managers should put in that place vector surveillance strategize with the assistance of health authorities.

Wherever the schistosomiasis is endemic, water contact should be prohibited and sanitation facilities enhanced (Reymond et al., 2009; Silverman et al., 2014).

In hyperendemic malaria conditions (like those prevailing in numerous parts of subSaharan Africa) wastewater pools might not posture an important extra risk,

however in meso endemic areas such as in Asia control actions will be significant (Sprenger et al., 2011).

These can be normal predators like tadpoles which are frequently present even in little ponds. Small ponds might also be sheltered with netting while bigger systems might require other techniques of biological control for example. Larvivorous fish such as Tilapia (Mansouri et al., 2010; Homski et al., 1994).

8.4. IMPROVING ON-FARM PONDS FOR WASTEWATER TREATMENT IN ACCRA, GHANA

8.4.1. Location

A big vegetable farming located in Accra where drain water and the contaminated stream is the usual irrigation water base for around 100 farmers. Individual pools and networks of interrelated ponds are usual. Networks are managed through 2 to above 20 farmers relying on their size. These systems enhance fecal coliform elimination from 10^6–10^7 MPN/100 ml through at least 2 log units from the wastewater base to the last pool. For instance for individual ponds, elimination of 1 to 1.5 log units was witnessed over two days. Helminth eggs were only rarely found in the water base at this location (up to two eggs per liter) and fell below one egg per liter in the first pond. A trial project was started to enhance a current 5 pond network for improved risk control. The project was worked out in a participating method with the farmers. Design alterations intent for reducing "short-circuiting" and doubling the water volume (rapid flow), to enhance the complete water retention time in the structures from 1 to 2 days (Al-Hamaiedeh and Bino, 2010; Al-Zu'bi et al., 2015).

8.4.2. Technology Description

Trenches were marginally expanded and ponds were excavated and their shape standardized. Some stairs were made to ease water fetching without the threat of re-entrainment of residue. Simple baffles were positioned in transit pools to enhance the retention time of water.Required inputs: Frequently labor for construction (2 man-days) and $50 per farmer for the construction materials (Figure 8.2).

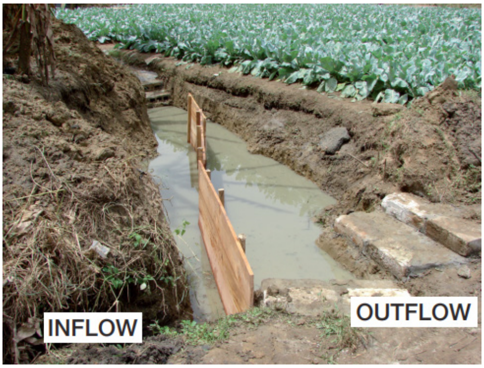


Figure 8.2: Interrelated pond with hardwood baffle.

8.4.3. Pathogen Removal

The first results show that the retention dugouts account for a fairly stable permanent enhancement and a flood gate (pipe-elbow or weir that can be turned) installed to halt the constant inflow of pathogen rich water from the main tributary throughout the watering period prohibited recontamination (Figure 8.3).

Figure 8.3: Well subsequent to a wastewater passage in Ouagadougou, Burkina Faso.

Source: https://www.who.int/water_sanitation_health/wastewater/FLASH_OMS_WSHH_Guidance_note4_20100729_17092010.pdf.

8.4.4. Adoption and Out-Scaling Potential

Pathogen decrease should preferably take place earlier or in the first pond to enhance food safety on the entire site. Therefore, additional upstream experiments have been initiated. Though this case doesn't demonstrate a perfect solution, it displays that structure farmers are already executing on their own expertise can contribute to pathogen decrease and also provide opportunities for enhancements by participatory research. Significant site criteria in this state were space, adequate tenure security to permit the set-up of structure and sufficient slope to permit flow by gravity for interrelated systems. Given the load of 2 watering cans of 151, 50 beds/farmer and 10 watering cycles/bed over the day, every decrease in transport facilitates farmers' collaboration. The system is not appropriate in areas inclined to flood (Reymond et al., 2009)

8.5. FILTRATION SYSTEMS

Table 8.2 displays some usual filtration systems for the treatment of wastewater at the farm level, using media like gravel, soil, and sand. In general, pathogen elimination is achieved through: a) holding pathogens through adsorption and straining in the media and b) predation and die-off. The first two instances in Table 8.2 are about technologies that have been familiarized; the third and fourth filtration methods are about technologies that are previously traditionally used by farmers (Tarjuelo et al., 2015).

Table 8.2: Outline of Common Filtration Structures for on-Farm Water Treatment

	1. Slow sand filters	**2. Gravel sand filters for greywater treatment**	**3. Soil filter systems**	**4. Strainers**
Description	Utilized for instance in feeding *drip irrigation systems* water containers, where unfiltered wastewater inclines to choke the outlets. Sand should be of accurate configuration for example effective size of 0.15 to 0.40 mm and a uniformity coefficient of 1.5 to 3.6.	Utilized in confined soil dugouts, for example, to treat greywater from households or small streams before irrigating flowers and crops. See Box 3 for an instance.	Wells are sunk 1 to 5 meters away from wastewater canals or streams with the objective of gathering shallow groundwater as witnessed in Ghana, Mali, and Burkina Faso. Canal water passes by the soil to the well following a hydraulic incline and is filtered in this procedure (see Figure 8.5).	In Senegal, Ghana, and Togo farmers use numerous materials like mosquito netting to avoid particles like waste, organic debris, and algae, from entering the watering cans while raising water. Filtration materials are too attached to the pumps.
Pathogen removal	1 to 3 log units for helminths and 0 to 3 log units for bacteria (WHO, 2006). In Ghana, 0.5 to 1 m deep column sand filters eliminated around 2 log units of bacteria and 71 to 96% of helminths.	Gravel under anaerobic situations facilitates biological treatment with 2 to 3 days of retention times Pathogens and entire suspended solids were decreased to 50%.	Pathogen elimination relies on subsurface flow distance and soil properties like texture Most efficient for larger pathogens like helminths and protozoa but less efficient for the elimination of viruses and bacteria.	The optimistic side effect is that pathogens adsorbed to the filtered organic matter are detached. Depending on the pathogen load and type of matter, up to 1 log unit elimination for bacteria and 12 to 62% for helminths was saw with a regular nylon cloth.

Challenges	The blockage of the filtration medium sand makes regular cleaning compulsory.	Relying on site, cleaning to avoid odors and with time blockage of the gravel media.	Termite tunnels or cracks in soil structure can permit pathogens to pass through deprived of being filtered.	Fine material is great efficient for the removal of an egg without disturbing water outflow or inflow. Constant removal of filtered remains.
References	(Metcalf and Eddy, Inc., 1995; Keraita et al., 2008b).	(Bino et al., 2008; WQSD, 2009).	(Cornish and Lawrence, 2001)	(Keraita et al., 2008b, 2010).

8.6. CONFINED TRENCH GRAVEL FILTER STRUCTURE FOR GREYWATER TREATMENT IN JORDAN

8.6.1. Location

The technology has been verified on diverse sites in Jordan, for instance in Karak it has been used for over 4 years to water the olive trees and downstream of the Jerash migrant camp where the water is used for horticultural production for above 1 year.

8.6.2. Technology Description

The system can assist a horticultural enterprise or a vast garden. Downstream of the Jerash campsite, greywater from a neighboring stream is diverted when required through a tube to the ditch. In the picture, the water enters the ditch in the area where the translucent plastic sheet is punctured to permit low water penetration.

From there the water moves gradually by gravity over the gravel layers to the container in front. The confined ditch is wrinkled with a dark water-resistant plastic sheeting around 400 microns thick and is filled with gravel. In Karak, there is 3 m^3 of gravel medium and 2 to 3 cm in diameter. The designed retention period is 2 to 3 days later which the filtered water arrives the container by a punctured lower part. From now, the water is propelled into a larger tank assisting an irrigation system. One unit can give up to 240 to 300 L/day, which is adequate to irrigate around 20 olive trees all over the year (Siebert and Döll, 2007).

8.6.3. Economic Assessment

In Karak, the price of 1 unit was estimated at $120 for site grounding, plastic sheets, gravel, and PVC pipes. Further installation of an electric pump, drip irrigation, and electric wiring would end in a total cost of $300. This amount could be reduced by using a lever pump. The average yearly operation and maintenance expense was projected to be $39. Based on the Net Current Values and benefit-cost ratio of 2.6 to 2.7, which were considered for different interest rates above 5 and 10 annum, the system showed to be economically possible.

8.6.4. Pathogen Removal

However, it was stated that the farm located near the Jerash campsite that entire suspended solids and pathogens were decreased to 50%, crops irrigated at Karak exhibited fecal coliforms within permissible limits for limited irrigation (Figure 8.4).

Figure 8.4: Treatment ditch at Jerash, Jordan.

Source: https://www.who.int/water_sanitation_health/wastewater/FLASH_OMS_WSHH_Guidance_note4_20100729_17092010.pdf.

8.6.5. Adoption and Up-Scaling Potential

Appropriate for small farms that have entrance to internal or external wastewater streams. Adoption might be high, particularly in drier climates and in sites with strict implementation of the water quality standards. Capacity building is essential for suitable operation and maintenance. The odor from the structure could put a challenge if people live adjacent (WQSD, 2009; Bino et al., 2008).

8.7. USE OF IRRIGATION INFRASTRUCTURE

However, not designed for the elimination of the pathogen, some parts of irrigation infrastructure like storage tanks and weirs (Figure 8.5) in irrigation systems can considerably enhance the microbiological quality of locally contaminated water. In the instance of the Musi River which passes through Hyderabad in India, the natural remediation effectiveness of the river system assisted through the construction of irrigation structure, especially weirs, was very high. It was found to decrease helminth eggs, BOD, and nitrogen, fecal coliforms at similar rates with the treatment effectiveness of a well-established waste steadiness pond system. The results displayed substantial improvement in the quality of water over a distance of 40 kilometers with 13 weirs, perhaps due to altered remediation procedures principally: aeration, natural die-off, exposure to Ultraviolet light, dilution, and sedimentation. Weirs evidenced to be especially effective traps for the helminth eggs (Table 8.3).

Based on the big quantity of eggs found in the residue of the irrigation channels, it is suggested to alter the design of suction pipes on electric water pumps to reduce the intake of residue. A choice might be U-shaped pipe ends which decrease.

Figure 8.5: Weir downstream of Hyderabad, India, and in Northern Laos.

Source:https://www.who.int/water_sanitation_health/wastewater/FLASH_OMS_WSHH_Guidance_note4_20100729_17092010.pdf.

Table 8.3: Utilization of Irrigation Infrastructure for Pathogen Decrease

	Weirs and tanks
Description	i. Weirs and water reservoirs in irrigation channels can facilitate pathogen elimination. ii. In irrigation systems in Hyderabad, India, weirs, which are used for regulating irrigation water, works as effective traps for the helminth eggs. iii. The same principle can relate to dams built by smallholders.
Pathogen removal	i. The study beside the Musi river exhibited that over a 40 kilometer stretch of the river ii. Helminth eggs had decreased from 133 eggs/l-0. *E. coli* levels displayed a decrease of above 4 log units from 7 log units per 100 ml.
Challenges	The positive influence of natural procedures for pathogen removal and options to improve them through normal irrigation infrastructure should be measured earlier to the financing in conventional wastewater treatment. The design and maintenance of irrigation structure might benefit from consideration of its probable positive influence on pathogen levels (for instance. through sedimentation and sediment management).

Source: Ensink et al. (2010).

To take benefit of current farm infrastructure and/or to construct new ones need full farmer contribution, particularly where awareness of risk is low, regulations are not imposed and marketing channels or demand for harmless produce are still missing. Participating in-farm research should be assisted through awareness creation, possible incentives (for example enhance tenure security, credit), and the survey of social marketing plans to enable technology adoption.

REFERENCES

1. Al-Hamaiedeh, H., & Bino, M., (2010). Effect of treated grey water reuse in irrigation on soil and plants. *Desalination*, *256*(1–3), 115–119.
2. Al-Zu'bi, Y., Ammari, T. G., Al-Balawneh, A., Al-Dabbas, M., Ta'any, R., & Abu-Harb, R., (2015). Ablution grey water treatment with the modified recirculated vertical flow bioreactor for landscape irrigation. *Desalination and Water Treatment*, *54*(1), 59–68.
3. Astudillo, M. F., Thalwitz, G., & Vollrath, F., (2015). Modern analysis of an ancient integrated farming arrangement: Life cycle assessment of a mulberry dyke and pond system. *The International Journal of Life Cycle Assessment*, *20*(10), 1387–1398.
4. Bhujel, R. C., (2013). On-farm feed management practices for Nile tilapia (Oreochromis niloticus) in Thailand. *On-farm Feeding and Feed Management in Aquaculture*, *583*, 159–189.
5. Bino, M., Al-Beiruti, S., & Ayesh, M., (2008). Greywater use in rural home gardens in Karek, Jordan. In: McIlwaine, S., & Redwood, M., (eds.), *Grey Water in the Middle East; Technical Social and Policy Issues* (Vol. 1, pp. 1–23). https://www.developmentbookshelf.com/doi/abs/10.3362/9781780440224.003.
6. Brochero, H. L., Rey, G., Buitrago, L. S., & Olano, V. A., (2005). Biting activity and breeding sites of Anopheles species in the municipality Villavicencio, Meta, Colombia. *Journal of the American Mosquito Control Association*, *21*(2), 182–186.
7. Cornish, G. A., & Lawrence, P., (2001). *Informal Irrigation in Peri-Urban Areas: A Summary of Findings and Recommendations* (Vol. 1, pp. 80–88). Report OD 144, H. R. Wallingford; Department for International Development.
8. Ensink, J. H., Mukhtar, M., Van, D. H. W., & Konradsen, F., (2007). Simple intervention to reduce mosquito breeding in waste stabilization ponds. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *101*(11), 1143–1146.
9. Ensink, J. H. J., Scott, C. A., Brooker, S., & Cairncross, S., (2010). Sewage disposal in the Musi-River, India: Water quality remediation through irrigation infrastructure. *Irrigation and Drainage Systems, 24*, 65–77
10. Flotats, X., Bonmatí, A., Fernández, B., & Magrí, A., (2009). Manure treatment technologies: On-farm versus centralized strategies. NE Spain as case study. *Bioresource Technology*, *100*(22), 5519–5526.

11. Gingrich, J. B., Anderson, R. D., Williams, G. M., O'Connor, L. I. N. D. A., & Harkins, K., (2006). Storm water ponds, constructed wetlands, and other best management practices as potential breeding sites for West Nile virus vectors in Delaware during 2004. *Journal of the American Mosquito Control Association*, *22*(2), 282–291.
12. Hatt, B. E., Fletcher, T. D., & Deletic, A., (2008). Hydraulic and pollutant removal performance of fine media storm water filtration systems. *Environmental Science and Technology*, *42*(7), 2535–2541.
13. Hirooka, K., Asano, R., Yokoyama, A., Okazaki, M., Sakamoto, A., & Nakai, Y., (2009). Reduction in excess sludge production in a dairy wastewater treatment plant via nozzle-cavitation treatment: Case study of an on-farm wastewater treatment plant. *Bioresource Technology*, *100*(12), 3161–3166.
14. IWMI, (2008a). *Good Farming Practices to Reduce Vegetable Contamination* (Vol. 1, pp. 1–23), Awareness, and training video for wastewater farmers. 16 min. CPWF, DVD. https://www.youtube.com/watch?v=Aa4u1_RblfM.
15. IWMI, (2008b). *Health Risk Reduction in a Wastewater Irrigation System in Urban Accra* (Vol. 1, pp. 1–33), Ghana. 7 min. https://www.youtube.com/watch?v=oVBDYge868k.
16. Jackson, C. J., Preston, N., Burford, M. A., & Thompson, P. J., (2003). Managing the development of sustainable shrimp farming in Australia: The role of sedimentation ponds in treatment of farm discharge water. *Aquaculture*, *226*(1–4), 23–34.
17. Jaffrin, M. Y., Ding, L. H., Akoum, O., & Brou, A., (2004). A hydrodynamic comparison between rotating disk and vibratory dynamic filtration systems. *Journal of Membrane Science*, *242*(1–2), 155–167.
18. Keraita, B., Drechsel, P., & Konradsen, F., (2008). Using on-farm sedimentation ponds to improve microbial quality of irrigation water in urban vegetable farming in Ghana. *Water Science and Technology*, *57*(4), 519–525.
19. Keraita, B., Drechsel, P., Klutse, A., & Cofie, O., (2014). *On-farm Treatment Options for Wastewater, Grey Water and Fecal Sludge with Special Reference to West Africa* (Vol. 1, pp. 1–44). IWMI.
20. Keraita, B., Drechsel, P., Konradsen, F., & Vreugdenhil, R. C., (2008b). 'Potential of simple filters to improve microbial quality of irrigation water used in urban vegetable farming in Ghana.' *Journal of*

Environmental Science and Health, Part A, 43(7), 749–755.

21. Keraita, B., Konradsen, F., & Drechsel, P., (2010). Farm-based measures for reducing microbiological health risks for consumers from informal waste water irrigated agriculture. In: Drechsel, P., Scott, C. A., Raschid-Sally, L., Redwood, M., & Bahri, A., (eds.), *Wastewater Irrigation and Health: Assessing and Mitigation Risks in Low-Income Countries* (Vol. 1, pp. 189–207). Earthscan-IDRC-IWMI, UK. https://pdfs.semanticscholar.org/ee58/7b25216d576cb55503c5f9dc265d9991a987.pdf.
22. Keraita, B., Drechsel, P, & Konradsen, F., (2008a). Using on-farm sedimentation ponds to improve microbial quality of irrigation water in urban vegetable farming in Ghana. *Water Science and Technology, 57*(4), 519–525
23. Mansouri, J., Harrisson, S., & Chen, V., (2010). Strategies for controlling bio fouling in membrane filtration systems: Challenges and opportunities. *Journal of Materials Chemistry*, *20*(22), 4567–4586.
24. Mara, D. D., Pearson, H. W., Oragui, J. I., Crawley, L. R., De, O. R., & Silva, S. A., (1996). *Wastewater Storage and Treatment Reservoirs in North-East Brazil*, *TPHE Research Monograph* (Vol. 12, pp. 1–32). University of Leeds, Department of Civil Engineering, Leeds.
25. Metcalf & Eddy, Inc., (1995). *Wastewater Engineering: Treatment, Disposal, and Reuse* (Vol. 1, pp. 18, 19). McGraw-Hill, New York, NY.
26. Mukhtar, M., Ensink, J., Van, D. H. W., Amerasinghe, F. P., & Konradsen, F., (2006). Importance of waste stabilization ponds and wastewater irrigation in the generation of vector mosquitoes in Pakistan. *Journal of Medical Entomology*, *43*(5), 996–1003.
27. Qadir, M., Mateo-Sagasta, J., Jiménez, B., Siebe, C., Siemens, J., & Hanjra, M. A., (2015). Environmental risks and cost-effective risk management in wastewater use systems. In: *Wastewater* (Vol. 1, pp. 55–72). Springer, Dordrecht.
28. Reymond, P., Cofie, O., Raschid, L., & Kone, D., (2009). Design considerations and constraints in applying on-farm wastewater treatment for urban agriculture. In: *4th SWITCH Scientific Meeting* (Vol. 4, pp. 4–7).
29. Reymond, P., Cofie, O., Raschid, L., & Koné, D., (2009). Design considerations and constraints in applying on-farm wastewater treatment for urban agriculture. *Paper Presented at the 4th SWITCH Scientific Meeting*, (Vol. 4, pp. 1–39). Delft, the Netherlands
30. Riaño, B., & García-González, M. C., (2014). On-farm treatment

of swine manure based on solid-liquid separation and biological nitrification-denitrification of the liquid fraction. *Journal of Environmental Management*, *132*, 87–93.

31. Riaño, B., & García-González, M. C., (2015). Greenhouse gas emissions of an on-farm swine manure treatment plant-comparison with conventional storage in anaerobic tanks. *Journal of Cleaner Production*, *103*, 542–548.
32. Siebert, S., & Döll, P., (2007). 2.4 Irrigation water use-A global perspective. *Central Asia*, *14*, 10–12.
33. Silverman, A. I., Akrong, M. O., Drechsel, P., & Nelson, K. L., (2014). On-farm treatment of wastewater used for vegetable irrigation: bacteria and virus removal in small ponds in Accra, Ghana. *Journal of Water Reuse and Desalination*, *4*(4), 276–286.
34. Sprenger, C., Lorenzen, G., Hülshoff, I., Grützmacher, G., Ronghang, M., & Pekdeger, A., (2011). Vulnerability of bank filtration systems to climate change. *Science of the Total Environment*, *409*(4), 655–663.
35. Symonds, E. M., Verbyla, M. E., Lukasik, J. O., Kafle, R. C., Breitbart, M., & Mihelcic, J. R., (2014). A case study of enteric virus removal and insights into the associated risk of water reuse for two wastewater treatment pond systems in Bolivia. *Water Research*, *65*, 257–270.
36. Tarjuelo, J. M., Rodriguez-Diaz, J. A., Abadía, R., Camacho, E., Rocamora, C., & Moreno, M. A., (2015). Efficient water and energy use in irrigation modernization: Lessons from Spanish case studies. *Agricultural Water Management*, *162*, 67–77.
37. Tourre, Y. M., Lacaux, J. P., Vignolles, C., Ndione, J. A., & Lafaye, M., (2008). Mapping of zones potentially occupied by *Aedes vexans* and *Culex poicilipes* mosquitoes, the main vectors of Rift Valley fever in Senegal. *Geospatial Health*, *3*(1), 69–79.
38. Water Quality Study Division, (WQSD), (2009). WHO/FAO/IDRC project on nontreatment options for the safe use of wastewater, excreta, and grey water in agriculture and aquaculture. *Final Report* (Vol. 1, pp. 1–44). Environmental Research Center, RSS, Amman, Jordan.
39. WHO, (2006). *Guidelines for the Safe Use of Wastewater, Excreta, and Grey Water: Wastewater Use in Agriculture* (Vol. 2, pp. 1–33); Geneva: WHO, FAO, UNEP.

INDEX

Agricultural Wastewater Treatment

For many centuries, wastewater has been inappropriately used in agriculture, causing potential dangers to the environment and public health. Scientific developments and growing water crisis have compelled the countries to treat and reuse wastewater in agriculture. This practice helps lessen the pressure of water use along with a reduction in environmental pollution. This book presents an overview that discusses the impacts, both negative and positive, of wastewater utilization in the agricultural environment, emphasizing the influence on the soil and aquatic environment. The literature unveils that, until the late 1990s, research studies encouraged the utilization of wastewater for irrigation from a treatment perspective, while suggesting conventional solutions. Nevertheless, more recent studies (2012–2016) show that agricultural reuse considerably affects the texture properties of soil, while also instigating potential modifications of the microbiota and biomass.

Irrigated agriculture yields 33% of the world's crop products and 50% return from worldwide crop production. However, in numerous areas of the world, particularly in arid and semiarid regions the future of irrigation-based agriculture is endangered by existing or projected freshwater shortages. These water shortages essentially result from the ever-growing demand for water by a rapidly growing global population and their elegant lifestyle. Water reuse (recycling), wastewater treatment, and the utilization of treated sewage effluents for industrial agriculture and nonpotable environmental and urban applications can offer a highly efficacious and sustainable approach to exploit water resources in regions afflicted by water shortage. This book essentially focuses on the reuse and treatment of agricultural wastewater to combat the issues of water scarcity and environmental pollution.

The book is divided into eight chapters. All the chapters briefly introduce the readers with fundamental and essential concepts of a topic related to agricultural wastewater treatment. The concepts of agricultural wastewater treatment cannot be understood without grasping the fundamentals related to agricultural wastewater treatment. Chapter 1 discusses the fundamental concepts of agricultural wastewater treatment. Chapter 2 focuses on the applications of wastewater resources. Chapter 3 briefly addresses the essential quality guidelines for agricultural wastewater. Chapter 4 addresses the topic of irrigation using wastewater.

Chapter 5 explains the fundamentals of sewage sludge use in agriculture. On the other hand, Chapter 6 focuses on the benefits and drawbacks of wastewater use in agriculture. Chapter 7 illustrates wastewater irrigation methods in developing countries. Finally, Chapter 8 discusses on-farm wastewater treatment technologies.

This book essentially covers a broad range of areas associated with the utilization and treatment of agricultural wastewater. It can serve as a ready reference for students, teachers, scientists, researchers, agronomists, ecologists, and engineers.

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