International Journal Of Multidisciplinary Research In Science, Engineering and Technology (IJMRSET)

| ISSN: 2582-7219 | www.ijmrset.com | Monthly Peer Reviewed Journal |

| Volume 1, Issue 2, December 2018 |

# Benefits and Risks of Wastewater Use in Agriculture

**Iqbal Singh**

Associate Professor in Zoology, Dr. Bhim Rao Ambedkar Govt. College, Sri Ganganagar, Rajasthan, India

**ABSTRACT:** Wastewater use in agriculture has substantial benefits, but can also pose substantial risks to public health especially when untreated wastewater is used for crop irrigation. Farmers often have no alternative but to use untreated wastewater because there is no wastewater treatment and freshwater is either unavailable or too expensive. The major risks to public health are microbial and chemical. Wastewater use in agriculture can also create environmental risks in the form of soil and groundwater pollution. However, if properly planned, implemented and managed, wastewater irrigation can have several benefits for the environment, as well as for agriculture and water resources management. Given these risks and benefits, countries seeking to improve wastewater use in agriculture must reduce the risks, in particular to public health, and maximize the benefits.

**KEYWORDS:** benefits, risks, wastewater, agriculture, treatment, pollution, management, resources, health, public

## I.INTRODUCTION

Water scarcity and stress is a prevalent concern of both developing and developed nations. The use of wastewater for agricultural activities is a growing solution to this problem as agricultural irrigation is a great freshwater consumer. The drivers to this practice include the rise in urbanization trends, the high demand for food, depleting water resources, and climate variability and change. Production patterns of wastewater showed that developed nations reclaim it while developing nations use it prior to treatment. Benefits affiliated to wastewater agriculture, such as easing the pressure on freshwater resources, expanded agricultural potential even in marginalized communities, and additional nourishment to soils and crops, are highlighted. Risks such as exposure to endocrine disrupters, trace organics, and heavy metals are discussed. Conclusively, wastewater use in agricultural activities has high potential, which can be optimized by adopting treatment technologies and policies that regulate its use toward environmental sustainability.

Wastewater is water that has been used domestically or in the industry. Wastewater contains many pollutants, biological and chemical and, therefore, must be treated before it can be reused for other purposes. Contaminants may include inorganic solids, dissolved solids, organic material, heavy metals, floating materials (oil and grease), microorganisms, nutrients etc. Treatment involves a variety of biological, chemical, as well as physical methods to reduce contaminant concentrations. Israel is one of the pioneering countries in wastewater treatment and reuse. Israel has always faced water shortages. Water supply in the country is dependent on water sources other than natural, such as desalination and reclaimed water. Therefore, Israel is well-known for its desalination capabilities. Israel has boosted economic growth and resilience to extreme droughts by wastewater reclamation thanks to investments worth $700 million in the past 20 years.

Most impressive of all is the way that Israel has revolutionized water recycling. It is the leader in water reclamation, having managed to recycle and treat about 90% of its wastewater. Most of its wastewater effluent is used for irrigating agricultural crops. About 10% of this is used for the country’s efforts in fighting fires and restoring river flows.

The use of wastewater in agriculture includes the provision of water and nutrients for cultivation and ensuring that cities have sufficient water supply. There are various benefits to using wastewater to irrigate crops or farmland.

High nutrient content: Wastewater is naturally rich in nutrients, which helps to reduce or eliminate the need for costly chemical fertilizers. This allows for people to be supported in less affluent communities and reduces the cost of running their farms.

It is environmentally friendly: Using wastewater to irrigate crops or farmland is a sustainable and low-cost way to conserve water and reduce wastage.

Higher crop production: Farmers can increase their yields by irrigation. This is because they have access to water and are able to plant more crops. Having water available throughout the year allows the growing season to be extended. In addition, irrigation allows farmers to plant crops in areas otherwise considered too dry. It acts as an ‘insurance policy’ against drought and seasonal variability.

Higher quality crops: Water stress can have a dramatic impact on farm produce quality. Higher availability of water eliminates water stress. Therefore, farmers can produce better quality crops and pastures through irrigation.

Increase the property’s value: Irrigated land can support more crops and animal production. This makes it more valuable. It is a common way to increase the property’s value.

## II.DISCUSSION

Not all wastewater is created equal.After primary treatment, which removes 50 to 70 per cent of suspended solids such as grit, oil, debris and oils, wastewater must be treated with secondary treatment in order to separate dissolved biosolids.These treatment methods can improve the wastewater quality, but they are not sufficient to ensure safe irrigation of crops. Pathogens can also be transported by spray irrigation onto fresh edible crops. There is also the possibility of cross-contamination between potable water and insufficiently treated wastewater. This includes people who come in contact with products contaminated with insufficiently processed wastewater.These risks can be eliminated by tertiary treatment that uses sand or membrane filtering and additional disinfection treatments to eliminate microbiological contaminants. It can then be distributed to the agricultural sector for vegetable crop irrigation, as well as other industries that require clean water like paper manufacturing and textiles manufacturing.

Treated wastewater should not be used to irrigate crops potentially sensitive to wastewater. However, it can be successfully used to irrigate both salt-tolerant and drought-tolerant crops such as certain types of trees, shrubs and fodders. Reusing wastewater should be of paramount concern as it will determine which crops can be irrigated.

Various trace elements and salts might limit the reuse of wastewater. High levels of trace elements can cause crop growth problems. Individual salts can also disrupt plant nutrient uptake. If water treatment is not done properly, it can lead to soil salinization or contamination of crops with biological and chemical residues.

Unstable soil structure can be caused by high sodium to calcium and magnesium ratios. Compaction, crusting, and quality degradation of soils can lead to soil instability, affecting crop growth. Therefore, the physical and chemical properties of soils that are irrigated with wastewater may change with time. The use of partially treated and untreated wastewater for irrigation is beneficial in agriculture but may be associated with human health risks. Reports from different locations globally have linked microbial outbreaks with agricultural reuse of wastewater. This article reviews the epidemiological evidence and health risks associated with this practice, aiming toward evidence-based conclusions. Exposure pathways that were addressed in this review included those relevant to agricultural workers and their families, consumers of crops, and residents close to areas irrigated with wastewater (partially treated or untreated). A meta-analysis gave an overall odds ratio of 1.65 (95% CI: 1.31, 2.06) for diarrheal disease and 5.49 (95% CI: 2.49, 12.10) for helminth infections for exposed agricultural workers and family members. The risks were higher among children and immunocompromised individuals than in immunocompetent adults. Predominantly skin and intestinal infections were prevalent among individuals infected mainly via occupational exposure and ingestion. Food-borne outbreaks as a result of crops (fruits and vegetables) irrigated with partially or untreated wastewater have been widely reported. Contamination of crops with enteric viruses, fecal coliforms, and bacterial pathogens, parasites including soil-transmitted helminthes (STHs), as well as occurrence of antibiotic residues and antibiotic resistance genes (ARGs) have also been evidenced. The antibiotic residues and ARGs may get internalized in crops along with pathogens and may select for antibiotic resistance, exert ecotoxicity, and lead to bioaccumulation in aquatic organisms with high risk quotient (RQ). Appropriate mitigation lies in adhering to existing guidelines such as the World Health Organization wastewater reuse guidelines and to Sanitation Safety Plans (SSPs). Additionally, improvement in hygiene practices will also provide measures against adverse health impacts.

## III.RESULTS

The use of wastewater in agriculture has limitations due to the risks associated with the different routes of exposure, exposed groups and concentrations of various physicochemical and microbiological parameters. Thus, soil as a means of receiving wastewater, the irrigation method, the type of irrigated crop, the products consumed, farmers and their families and final consumers, are exposed throughout the process chain .With the development of the WHO guidelines of 1989, it was recognized that human parasites are the main risk to human health and the development of wastewater treatment systems for risk reduction was proposed as the main strategy. Thus, the concept of “zero risk” could only be achieved under technological schemes of primary, secondary and disinfection treatment, technically feasible but not a feasible solution in the practical and economic context of developing countries .

With the development of the WHO guidelines of 2006, the need to know the magnitude of the risk associated with this type of practice was clearly formulated and the conceptual bases for its estimation were formulated, recognizing with this that strategies for risk reduction should be flexible and adjusted to the local context and for the first time suppressed the effluent quality thresholds .Thus, the concept of “multiple barriers” was introduced. It proposed a series of barriers along the reuse chain, instead of focusing only on treatment infrastructure for the improvement of wastewater quality to be reused .The WHO guidelines (2006) raised the health-based goals, which are estimated from a standard measure of disease selected in relation to the Disability Adjusted Life Year (DALY). DALY is a quantitative indicator of disease burden, which represents the total amount of healthy life reduced because of a disability, or the lifetime that is lost due to premature mortality. The objective formulated corresponded to $\leq 10^{-6}$ DALY per person, which is the estimated disease burden associated with mild diarrhea .

According to the literature, the risk assessment can be performed using three types of studies: (i) microbiological laboratory tests; (ii) epidemiological studies; and (iii) quantitative microbiological risk assessment (QMRA). Microbiological studies are considered as a source of information for types of studies (ii) and (iii) and are only appropriate if health assessments and appropriate protective measures are taken to avoid a health risk .Epidemiological studies are a direct measure of the associated risk, but their complexity and target population requirements and high costs may limit the technique .The QMRA is considered an indirect risk measurement that has been widely used, but its results are associated with the specific scenarios evaluated . The combined use of the three types of studies for risk estimation may yield better results in their evaluation, notwithstanding the costs associated with each type of study, the population size and time required, the required input information, and the difficulty of modeling, are some of the limitations that determine the prioritization of the use or the combined use of these tools .

Quantitative microbiological risk assessment (QMRA) has been considered an essential component of risk management .A probabilistic modeling technique to estimate the magnitude of risk under specific scenarios and its implementation is defined in four steps: (i) hazard identification; (ii) exposure assessment; (iii) dose–response modeling; and (iv) risk characterization. The use of this technique in relation to the wastewater reuse in agriculture has been focused on the risk assessment in raw consumer products, especially on varieties of lettuce and some vegetables, and rotavirus infection as a major cause of diarrheal disease in the world .

In 1992, a review of the data accumulated in the period from 1975 to 1989 led to the reformulation of the quality criteria of wastewater of the state of California (United States). Based on the above, a comparative study was carried out of the possible risks of enteric virus infection with secondary and tertiary effluents from treatment systems, as opposed to four exposure scenarios for wastewater use (irrigation of food crops, golf courses, recreational reservoirs and the recharge of aquifers). The analyzes of this study showed that the annual risk of exposing a tertiary effluent with chlorine disinfection, with a viral unit content of 100 L, entails an associated risk in golf courses and recreational reservoirs in a range of $10^{-2}$ to $10^{-7}$, while in crop irrigation and aquifer recharge, it may have an associated risk between $10^{-6}$ and $10^{-11}$ .These are determining results for the formulation of mitigation strategies and the prioritization of the investment.

Quantitative microbiological risk assessments associated with virus in lettuce crops have been the most commonly evaluated. Petterson et al. evaluated the impact of two risk factors: (i) the density function associated with the occurrence of human enterovirus in irrigation water; and (ii) the mortality rates for the virus in lettuce cultivation. Under an application of the Monte Carlo simulation method, researchers observed that changes in density function had minimal variations in estimated infection rates. However, the predicted infection rates were more sensitive than the virus decay rates.

Hamilton et al. designed a Decision Support tool called RIRA (Recycled water Irrigation Risk Analysis). This tool helps water and public health managers to conduct Quantitative Microbiological Risk Assessments. RIRA was designed to simulate a wide range of scenarios by defining the pathogen of interest and the exposure scenario, using specific dose–response models. The main advantage of RIRA is its generic and flexible structure, which can be used to carry out risk assessments in accordance with the methods recommended in the main guidelines on recycled water and local context scenarios.

Barker et al. developed a QMRA model to estimate the burden of norovirus disease associated with the consumption of irrigated lettuce with untreated gray water, a practice commonly performed in Australia and not endorsed by normative guidelines. The estimated annual disease burden fluctuated over a range of $2 \times 10^{-8}$ and $5 \times 10^{-4}$ depending on the source of gray water and of how thoroughly the consumer washes the product at home. The model predicted disease loads of $4 \times 10^{-9}$ and $3 \times 10^{-6}$ for bath and washing waters respectively. Using these results, the authors recommended the use of bath water that conforms to normative standards in Australia (threshold value $10^{-6}$ DALY per person). In addition, in Australia, a QMRA model was developed to know the risk of irrigation with wastewater in other types of vegetables such as lettuce, broccoli, cabbage, Asian vegetables and cucumber. Norovirus concentration was used, using faecal dumping rates in black wastewater and the annual norovirus disease burden after irrigation with treated wastewater .The annual estimates of disease burden showed that the primary treatment scenarios evaluated fluctuated within a range of $10^{-5}$ to $10^{-3}$ DALY per person, exceeding all mean values suggested by the WHO and Australian regulations (threshold $\leq 10^{-6}$ DALY per person). However, in the advanced treatment scenarios, most of the cucumber consumption scenarios obtained mean values of disease burden that met the threshold. In general, lettuce consumption posed the greatest risks, while cucumber consumption had the lowest risks. This research was relevant because it was the first QMRA to consider viral accumulation by irrigation using wastewater.

Hamilton and Mok conducted an experiment to determine the volume of water collected in Asian vegetables and lettuce after irrigation by sprinkling with wastewater. The proposed objective contributed to the decrease in the knowledge gap, associated with the estimation of rotavirus microbiological risk in high consumption products in China. Four vegetables were evaluated. The predicted annual probability of infection was $7 \times 10^{-4}$ for the consumption of *bok choy*, $4 \times 10^{-3}$ for *choy* and $2 \times 10^{-3}$ for him *gai lan* and lettuce. Likewise, the annual average disease burden ranged between $5 \times 10^{-6}$ DALY per person and $3 \times 10^{-5}$ DALY per person for the consumption of *bok choy* and *suma choy*, respectively. The disease burden for *gai lan* and lettuce was $2 \times 10^{-5}$ DALY per person. This was the first presentation of water retention measurements for Asian vegetables, as well as the first viral risk assessment for the consumption of vegetables from wastewater in China. This research is significant because China is home to one-fifth of the world's population, and because of the availability of data on rotavirus concentrations, documented as the predominant cause of diarrheal disease in children .

Another study was conducted in Ghana to assess the risk associated with water used in the irrigation of vegetables. Pollution parameters evaluated were fecal coliforms and helminth eggs. The water quality was monitored during two months and their concentration levels ranged from 3 to 4 log units of fecal coliforms in 100 mL and from 6 to 15 eggs of helminth per L. Regarding the evaluated product of consumption (lettuce) the concentration of fecal coliforms ranged from $7 \times 10^{2}$ and $1.8 \times 10^{3}$ in 10 g and the helminth eggs ranged from 6 to 9 per 100 g. The annual risk of infection was $10^{-2}$ for Ascaris and $10^{-1}$ for *E. coli*. This study is relevant for its development in the risk assessment for possible infections caused by helminths and *E. coli* .

According to Jiménez et al. the lack of scientific knowledge related to the use of wastewater still resides in the evaluation of the microbiological risk associated with the infection caused by helminths. The WHO and EPA guidelines were based on limited epidemiological evidence, rather than the results of a risk assessment. None of these organizations based their recommendations on dose–response curve results, because methodologies had not been sufficiently developed. At the moment, only the risk concerning helminths has been evaluated through laboratory analysis and epidemiological studies. This fact contrasts the development of multiple dose–response models for bacteria, viruses and protozoa. Despite the fact that the WHO recognized that helminths represent a real risk of infection due to its resistance and persistence in the environment and to the minimum infective dose, the development of measurement techniques of this microorganism are in early stages, which depend on direct observation under the microscope with this subjectivity in the results .In addition, in developing countries, regulations do not commonly associate helminths and protozoa, because in these countries, intestinal worm diseases are low among the population.

Globally, agriculture is a major consumer of wastewater. The search for alternative irrigation sources is believed to be vital to ensure food safety and to preserve natural water bodies. The safe use of wastewater, as an alternative source of irrigation, is an acknowledged strategy for the efficient use and prevention of water pollution that is gaining increasing relevance worldwide, especially in countries confronted with water shortages. However, there are risks associated with this type of use that must be assessed against a local framework, considering soil as a receiving environment and ensuring pollution will not be transferred from one medium to another (water to soil). Country efforts should be targeted at quantitative risk assessments. This would allow a more optimal and prioritized management considering that agricultural reuse can cause a very real public health problem if the risk is not taken into account.

The risks of wastewater reuse in agriculture are extensive, ranging from changes to physicochemical and microbiological properties of soils to impacts on human health. In unfavorable economic conditions, the search for alternative irrigation sources irrigation, such as the reuse of raw or inadequately treated wastewater may result in avoidable risk factors. Thus, it is necessary to communicate the beneficial aspects of this practice, as well as the negative impacts and different low-cost strategies that contribute to the decision-making process and favor the adequate use of wastewater in agriculture.

The lack of quantitative evaluation of microbiological risk, referring to the concentration of helminths, is the missing piece that is required for the proper implementation of agricultural reuse. This deficiency has promoted the use of raw sewage water, triggered by the incipient development of norms and the standards of some countries that do not conform to global guidelines. In addition, the improvement of the detection technique of helminths should be the next milestone to eliminate subjectivity and to advance the safe reuse of residual water.

**Implications**

Health protection measures which can be applied in agricultural use of wastewater include the following, either singly or in combination:

- Wastewater treatment
- Crop restriction
- Control of wastewater application
- Human exposure control and promotion of hygiene

In the past, wastewater treatment has been widely adopted as the major control measure in controlled effluent use schemes, with crop restriction being used in a few notable cases. A more integrated approach to the planning of wastewater use in agriculture will take advantage of the optimal combination of the health protection measures available and allow for any soil/plant contraints in arriving at an economic system suited to the local sociocultural and institutional conditions.

A WHO (1989) Technical Report on 'Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture' discusses the integration of the various measures available to achieve effective health protection. Limitations of the administrative or legal systems in some countries will make some of these approaches difficult to apply, whereas shortage of skilled technical staff in other countries will place doubt upon reliance on wastewater treatment as the only control mechanism. To achieve greater flexibility in the use of wastewater application as a health protection measure, irrigation systems must be developed to be capable of delivering low quality wastewater and restrictions on irrigation technique and crops irrigated must become more common.

Of the health protection measures mentioned above, only human exposure control is not dealt with in greater depth in later chapters of the Manual. The objective with this approach is to prevent the population groups at risk from coming into direct contact with pathogens in the wastewater or to prevent any contact with the pathogens leading to disease. Four groups are at risk in agricultural use of wastewater:

- agricultural workers and their families
- crop handlers
- consumers of crops, meat and milk
- those living near the areas irrigated with wastewater

and different methods of exposure control might be applied for each group.

Control measures aimed at protecting agricultural field workers and crop handlers include the provision (and insistence on the wearing) of protective clothing, the maintenance of high levels of hygiene and immunization against (or chemotherapeutic control of) selected infections. Examples of these measures are given in the WHO (1989) Technical Report mentioned. Risks to consumers can be reduced through cooking the agricultural produce before consumption and by high standards of food hygiene, which should be emphasized in the health education associated with wastewater use schemes. Local residents should be kept fully informed on the use of wastewater in agriculture so that they, and their children, can avoid these areas. Although there is no evidence to suggest that those living near wastewater-irrigated fields are at significant risk, sprinklers should not be used within 100 m of houses or roads.

Special care must always be taken in wastewater use schemes to ensure that agricultural workers or the public do not use wastewater for drinking or domestic purposes by accident or for lack of an alternative. All wastewater channels, pipes and outlets must be clearly marked and preferably painted a characteristic colour. Wherever possible, outlet fittings should be designed/selected so as to prevent misuse.

Following several meetings of environmental specialists and epidemiologists, a WHO Scientific Group on Health Aspects of Use of Treated Wastewater for Agriculture and Aquaculture arrived at the microbiological quality quidelines for wastewater use in agriculture shown in Table . These guidelines were based on the consensus view that the actual risk associated with irrigation with treated wastewater is much lower than previously thought and that earlier standards and guidelines for effluent quality, such as the WHO (1973) recommended standards, were unjustifiably restrictive, particularly in respect of bacterial pathogens.

Table 1 : Recommended microbiological quality guidelines for wastewater use in agriculture[a]

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

[a] In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and the guidelines modified accordingly.

[b] *Ascaris* and *Trichuris* species and hookworms.

[c] During the irrigation period.

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

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

Source: WHO (1989)

The new guidelines are stricter than previous standards in respect of the requirement to reduce the numbers of helminth eggs (*Ascaris* and *Trichuris* species and hookworms) in effluents for Category A and B conditions to a level of not more than one per litre. Also implied by the guidelines is the expectation that protozoan cysts will be reduced to the same level as helminth eggs. Although no bacterial pathogen limit is imposed for Category C conditions where farm workers are the only exposed population, on the premise that there is little or no evidence indicating a risk to such workers from bacteria, some degree of reduction in bacterial concentration is recommended for any effluent use situation.

The WHO Scientific Group considered the new approach to effluent quality would increase public health protection for the large numbers of people who were now being infected in areas where crops eaten uncooked are being irrigated in an unregulated, and often illegal, manner with raw wastewater. It was felt that the recommended guidelines, if adopted, would achieve this improvement and set targets which are both technologically and economically feasible. However, the need to interpret the guidelines carefully and modify them in the light of local epidemiological, sociocultural and environmental factors was also pointed out.

The effluent quality guidelines in Table  are intended as design goals for wastewater treatment systems, rather than standards requiring routine testing of effluents. Wastewater treatment processes achieving the recommended microbiological quality consistently as a result of their intrinsic design characteristics, rather than by high standards operational control, are to be preferred. In addition to the microbiological quality requirements of treated effluents used in agriculture, attention must also be given to those quality parameters of importance in respect of groundwater contamination and of soil structure and crop productivity.

Although heavy metals may not be a problem with purely domestic sewage effluents, all these elements are potentially present in municipal wastewater.

## IV.CONCLUSIONS

Traditionally, irrigation water is grouped into various quality classes in order to guide the user to the potential advantages as well as problems associated with its use and to achieve optimum crop production. The water quality classifications are only indicative guidelines and their application will have to be adjusted to conditions that prevail in the field. This is so because the conditions of water use in irrigation are very complex and difficult to predict. The suitability of water for irrigation will greatly depend on the climatic conditions, physical and chemical properties of the soil, the salt tolerance of the crop grown and the management practices. Thus, classification of water for irrigation will always be general in nature and applicable under average use conditions.

Many schemes of classification for irrigation water have been proposed. Ayers and Westcot (FAO 1985) classified irrigation water into three groups based on salinity, sodicity, toxicity and miscellaneous hazards, as shown in Table . These general water quality classification guidelines help to identify potential crop production problems associated with the use of conventional water sources. The guidelines are equally applicable to evaluate wastewaters for irrigation purposes in terms of their chemical constituents, such as dissolved salts, relative sodium content and toxic ions. Several basic assumptions were used to define the range of values in the guidelines and more detailed information on this is reported by Ayers and Westcot (FAO 1985).

The effect of sodium ions in irrigation water in reducing infiltration rate and soil permeability is dependent on the sodium ion concentration relative to the concentration of calcium and magnesium ions (as indicated by SAR) and the total salt concentration, as shown in the guidelines. It is graphically illustrated in Figure 4 which clearly indicates that, for a given SAR value, an increase in total salt concentration is likely to increase soil permeability and, for a given total salt concentration, an increase in SAR will decrease soil permeability. This illustrates the fact that soil permeability (including infiltration rate and surface crusting) hazards caused by sodium in irrigation water cannot be predicted independently of the dissolved salt content of the irrigation water or that of the surface layer of the soil.

Table : Guidelines for interpretation of water quality for irrigation

| Potential irrigation problem | Units | Degree of restriction on use | | |
|---|---|---|---|---|
| | | None | Slight to moderate | Severe |
| Salinity | | | | |
| $Ec_w^1$ | dS/m | < 0.7 | 0.7 - 3.0 | > 3.0 |
| or | | | | |
| TDS | mg/l | < 450 | 450 - 2000 | > 2000 |
| Infiltration | | | | |
| $SAR^2$ = 0 - 3 and $EC_w$ | | > 0.7 | 0.7 - 0.2 | < 0.2 |
| 3 -6 | | > 1.2 | 1.2 - 0.3 | < 0.3 |
| 6-12 | | > 1.9 | 1.9 - 0.5 | < 0.5 |
| 12-20 | | > 2.9 | 2.9 - 1.3 | < 1.3 |
| 20-40 | | > 5.0 | 5.0 - 2.9 | < 2.9 |
| Specific ion toxicity | | | | |
| Sodium (Na) | | | | |

| | | | | |
|---|---|---|---|---|
| Surface irrigation | SAR | < 3 | 3 - 9 | > 9 |
| Sprinkler irrigation | me/I | < 3 | > 3 | |
| Chloride (Cl) | | | | |
| Surface irrigation | me/I | < 4 | 4 - 10 | > 10 |
| Sprinkler irrigation | $m^3/l$ | < 3 | > 3 | |
| Boron (B) | mg/l | < 0.7 | 0.7 - 3.0 | > 3.0 |
| Trace<br>(see table ) | | | | Elements |
| Miscellaneous effects | | | | |
| Nitrogen ($NO_3$-N)[3] | mg/l | < 5 | 5 - 30 | > 30 |
| Bicarbonate ($HCO_3$) | me/I | < 1.5 | 1.5 - 8.5 | > 8.5 |
| pH | Normal range 6.5-8 | | | |

[1] $EC_w$ means electrical conductivity in deciSiemens per metre at 25°C
[2] SAR means sodium adsorption ratio
[3] $NO_3$-N means nitrate nitrogen reported in terms of elemental nitrogen

Municipal wastewater effluents may contain a number of toxic elements, including heavy metals, because under practical conditions wastes from many small and informal industrial sites are directly discharged into the common sewer system. These toxic elements are normally present in small amounts and, hence, they are called trace elements. Some of them may be removed during the treatment process but others will persist and could present phytotoxic problems. Thus, municipal wastewater effluents should be checked for trace element toxicity hazards, particularly when trace element contamination is suspected.

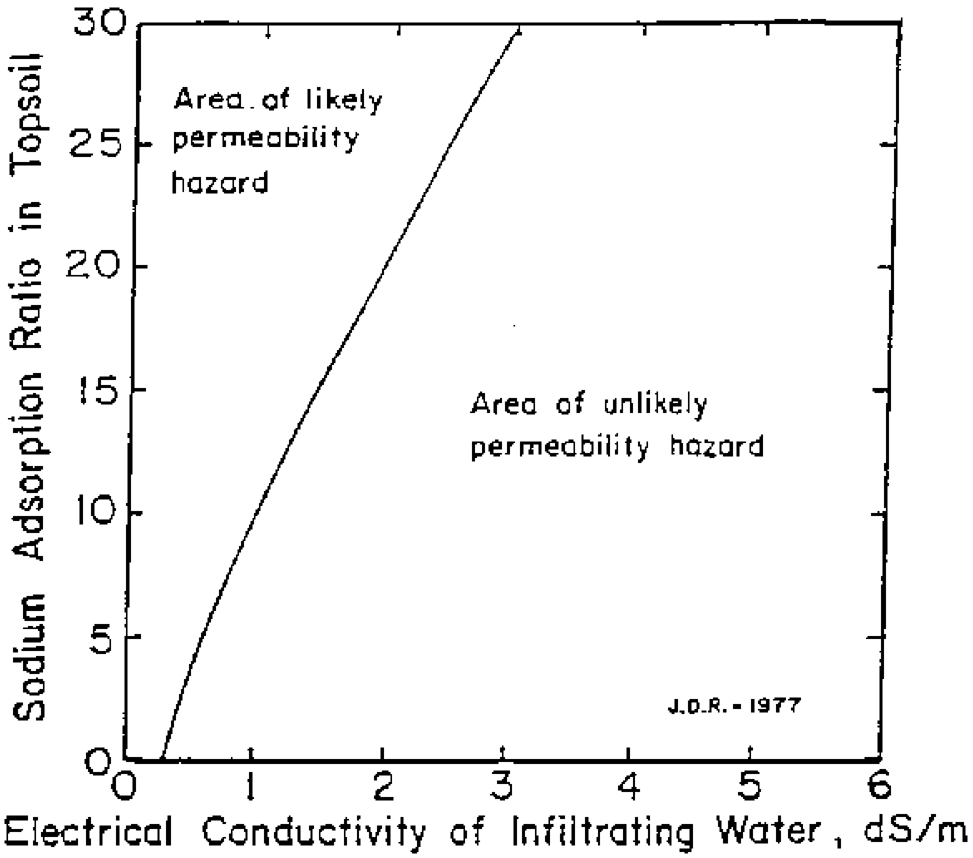
Table : Threshold levels of trace elements for crop production

| Element | Recommended maximum concentration (mg/l) | Remarks |
|---|---|---|
| Al (aluminium) | 5.0 | Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity. |
| As (arsenic) | 0.10 | Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice. |
| Be (beryllium) | 0.10 | Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans. |
| Cd (cadmium) | 0.01 | Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans. |
| Co (cobalt) | 0.05 | Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils. |
| Cr (chromium) | 0.10 | Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants. |
| Cu (copper) | 0.20 | Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions. |
| F (fluoride) | 1.0 | Inactivated by neutral and alkaline soils. |
| Fe (iron) | 5.0 | Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings. |
| Li (lithium) | 2.5 | Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low |

| | | |
|---|---|---|
| | | concentrations (<0.075 mg/l). Acts similarly to boron. |
| Mn (manganese) | 0.20 | Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils. |
| Mo (molybdenum) | 0.01 | Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum. |
| Ni (nickel) | 0.20 | Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH. |
| Pd (lead) | 5.0 | Can inhibit plant cell growth at very high concentrations. |
| Se (selenium) | 0.02 | Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. As essential element to animals but in very low concentrations. |
| Sn (tin) | | |
| Ti (titanium) | - | Effectively excluded by plants; specific tolerance unknown. |
| W (tungsten) | | |
| C (vanadium) | 0.10 | Toxic to many plants at relatively low concentrations. |
| Zn (zinc) | 2.0 | Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils. |

[1] The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10 000 $m^3$ per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 $m^3$ per hectare per year. The values given are for water used on a continuous basis at one site.

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



The measures which can be taken to protect health in aquacultural use of wastewater are the same as in agricultural use, namely wastewater treatment, crop restriction, control of wastewater application and human exposure control and promotion of hygiene. For the protection of workers in aquaculture ponds, the quality of the water is of paramount importance, as it is in respect of the contamination of fish or plants grown in excreta-fertilized or wastewater ponds. Transmission of pathogens can occur through persons handling and preparing contaminated fish or aquatic plants, which make human exposure control and hygiene important features of aquaculture programmes. Both the treatment applied to excreta, nightsoil or wastewater before introduction to an aquaculture pond and the rate of waste application will have an effect on the quality of water in the pond. In the past, these factors have not been controlled for health reasons but rather so as to ensure that a pond is not overloaded organically or chemically to the point where it will not support fish life or be suitable for the growth of aquatic plants. Reliance has been placed primarily on minimizing the risk of pathogen transmission through consumption by thorough cooking of the products. This has not always been satisfactory and, where the pond products are eaten uncooked, no health protection is provided. In some aquacultural practices, for example in rural Indonesia, depuration techniques are used in attempting to decontaminate fish in the period immediately preceding harvesting.

A number of human excreted helminthic pathogens, when released to aquaculture ponds, can involve fish or aquatic plants as intermediate hosts. Strauss (1985) has listed the following trematode infections as being capable of transmission in this way:

*Clonorchis*
*Heterophys*
*Opistorchis*
*Metagonimus*
*Diphyllobothrium*

However, he indicated that only clonorchiasis (liver fluke) and the closely related opistorchiasis have been transmitted through fish grown in excrete-fertilized or wastewater (freshwater) ponds. The first phase of development of these pathogens occurs in specific snails or copepods (minute crustaceans), with fish acting as a second intermediate host. These helminthic infections have significant public health importance in Asia, where fish are sometimes eaten raw. Strauss also pointed out that the helminthic pathogens *Fasciola* (sheep and cattle liver flukes) and *Fasciolopsis* (giant intestinal fluke) have the same pattern of life cycle but depend on aquatic plants, such as water chestnut, water cress and water bamboo, as secondary intermediate hosts onto which free-swimming cercariae become attached and where they encyst.

Aquatic snails also serve as intermediate hosts for the trematode-genus *Schistosoma* which is the causative agent of schistosomiasis (bilharzia). Transmission can occur when workers wade into aquaculture ponds in which infected snails are present and the larval schistosome penetrates the skin. This occupational hazard exists only where this disease is endemic and where snail hosts are present in aquaculture ponds. Schistosome infection, particularly *Schistosoma japonicum,* has been identified in excreta-fertilized fish ponds.

Fish grown in excreta-fertilized or wastewater ponds may also become contaminated with bacteria and viruses and serve as a potential source of transmission of infection if the fish are eaten raw or undercooked. Pathogenic bacteria and viruses may be passively carried on the scales of fish or in their gills, intraperitoneal fluid, digestive tract or muscle. Strauss (1985) reviewed the limited literature on excreted bacteria and virus survival in fish and concluded that:

- invasion of fish muscle by bacteria is likely to occur if the concentrations of faecal coliforms and salmonellae in the pond are greater than $10^4$ and $10^5$ per 100 ml, respectively;

- the potential for muscle invasion increases with the duration of exposure of the fish to contaminated pond water;

- little accumulation of enteric microorganisms and pathogens on, or penetration into, edible fish tissue occurs when the faecal coliform concentration in the pond water is below $10^3$ per 100 ml;

- even at lower pond water contamination levels, high pathogen concentrations might be present in the digestive tract and the intraperitoneal fluid of the fish;

- pathogen invasion of the spleen, kidney and liver has been observed.

Because only limited experimental and field data on the health effects of sewage-fertilized aquaculture are available, the WHO Scientific Group on Health Aspects of Use of Treated Wastewater for Agriculture and Aquaculture could suggest only a tentative bacterial guideline for the quality of aquaculture pond water. The tentative bacterial guideline suggested is a geometric mean number of faecal coliforms of □ $10^3$ per 100 ml (WHO, 1989). Furthermore, in view of the dilution of wastewater which normally occurs in aquaculture ponds, this ambient bacterial indicator concentration could be achieved, the Scientific Group suggested, by treating wastewater fed to ponds to a level of $10^3$-$10^4$ faecal coliforms / 100 ml. Such a guideline should ensure that invasion of fish muscle is prevented but pathogens might accumulate in the digestive tract and intraperitoneal fluid of fish. This might then create a health risk, through cross-contamination of fish flesh or other edible parts and transmission to consumers, if standards of hygiene in fish preparation are inadequate. High standards of hygiene during fish handling and, especially, gutting are necessary and cooking of fish is an important health safeguard. Similar considerations apply to the preparation and cooking of aquatic plants.

Table :Bacteriological quality of fish from excreta-reuse systems

| Total aerobic bacterial concentration in fish muscle tissue, bacteria/g | Fish quality |
|---|---|
| 0- 10 | Very good |
| 10- 30 | Medium |
| > 50 | Unacceptable |

Source: Buras *et al.* (1987)

Buras et al. (1985, 1987) have questioned the value of faecal coliforms as bacterial indicators for fish muscle because, in their studies, they were not always detected, whereas total aerobic bacteria (standard plate count) were. They proposed that total aerobic bacteria should be the indicators on the grounds that, if they were detectable in the fish, there was a chance that pathogenic bacteria would also be present. Consequently, the bacteriological standards for fish raised in excreta-fertilized and wastewater ponds indicated in Table  were recommended by Buras et al. (1987). A more recent State-of-the-Art-Review of Reuse of Human Excreta in Aquaculture (Edwards, 1990) discussed this issue and suggested that it was unlikely that fish will be of an unacceptable bacteriological quality when raised in excreta-fed ponds that are well-managed from an aquacultural point of view to produce good fish growth. That is, fish ponds loaded with excreta at a level which leads to the development of a relatively large biomass of phytoplankton, serving as natural food for the fish, but with adequate levels of dissolved oxygen maintained in the water, for the fish, should produce fish with acceptable bacteriological quality.

Transmission of the helminthic infections clonorchiasis and fasciolopsiasis occurs only in certain areas of Asia and can be prevented only by ensuring that no trematode eggs enter the pond or by snail control. Similar considerations apply to the control of schistosomiasis in areas where this disease is endemic. The Scientific Group (WHO, 1989) recommended an appropriate helminth quality guideline for all aquacultural use of wastewater as the absence of viable trematode eggs.

## REFERENCES

1. Brega Filho, D.; Mancuso, P.C. *Reúso de Água*; Universidade de São Paulo-Facultade de Saúde Pública: São Paulo, Brasil, 2003; p. 579. [Google Scholar]
2. Manga, J.; Logreira, N.; Serrait, J. Reuso de aguas residuales: Un recurso hídrico disponible. *Ingeniería y Desarrollo* 2001, *9*, 12–21. [Google Scholar]
3. Jaramillo, M.F. Potencial de Reuso de Aguas Residuales Domesticas como Estrategia de Prevención y Control de la Contaminación en el Valle Geográfico del rio Cauca. Master's Thesis, Universidad del Valle, Cali, Colombia, 2014. [Google Scholar]
4. Angelakis, A.; Snyder, S. Wastewater treatment and reuse: Past, present, and future. *Water* 2015, *7*, 4887–4895. [Google Scholar] [CrossRef]
5. Angelakis, A.; Gikas, P. Water reuse: Overview of current practices and trends in the world with emphasis in eu states. *Water Util.* 2014, *8*, 67–78. [Google Scholar]
6. Tzanakakis, V.; Paranychianaki, N.; Angelakis, A. Soil as a wastewater treatment system: Historical development. *Water Sci. Technol. Water Suppl.* 2007, *7*, 67–75. [Google Scholar] [CrossRef]
7. Cooper, P. Historical aspect of wastewater treatment. In *Decentralised Sanitation Reuse: Concepts, System and Implementation*; IWA Publishing: London, UK, 2001; pp. 11–38. [Google Scholar]
8. Drechsel, P.; Scott, A.; Sally, R.; Redwood, M.; Bachir, A. *Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-Income Countries*; International Water Management Institute, Ed.; Earthscan: London, UK, 2010. [Google Scholar]
9. Tzanakakis, V.; Koo-Oshima, S.; Haddad, M.; Apostolidis, N.; Angelakis, A. The history of land application and hydroponic systems for wastewater treatment and reuse. In *Evolution of Sanitation and Wastewater Technologies through the Centuries*; IWA Publishing: London, UK, 2014; p. 457. [Google Scholar]
10. Felizatto, M. Projeto integrado de tratamento avançado e reúso direto de águas residuárias. In Proceedings of the 21 Congresso Brasileiro de Engenharia Sanitária e Ambiental, João Pessoa, Brasil, 16–21 September 2001; pp. 1–17. [Google Scholar]
11. Seguí, A. Sistemas de Regeneración y Reutilización de Aguas Residuales. Metodología para el Análisis Técnico-Económico y Casos. Ph.D. Thesis, Universidad Politécnica de Cataluña Espana, Barcelona, Spain, 2004. [Google Scholar]
12. Barona, J.; Mestre, J. *La Salud y el Estado: El Movimiento Sanitario Internacional y la Administración Española (1815–1945)*; Universitat de València: València, Spain, 2008. [Google Scholar]
13. Asano, T.; Burton, F.; Leverenz, H.; Tsuchihashi, R.; Tchobanoglous, G. *Water Reuse: Issues, Technologies and Applications*; McGraw Hill Professional: New York, NY, USA, 2007. [Google Scholar]
14. Asano, T.; Levine, A. Wastewater reclamation, recycling and reuse: Past, present, and future. *Water Sci. Technol.* 1996, *33*, 1–14. [Google Scholar]
15. Jiménez, B.; Asano, T. *Water Reuse: An International Survey of Current Practice, Issues and Needs*; IWA Publishing: London, UK, 2008. [Google Scholar]
16. Carr, R. Who guidelines for safe wastewater use-more than just numbers. *Irrig. Drain.-Chichester* 2005, *54*, 103–111. [Google Scholar] [CrossRef]
17. WHO. *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture*; WHO: Geneva, Switzerland, 1989. [Google Scholar]

18. Kamizoulis, G. Setting health based targets for water reuse (in agriculture). *Desalination* 2008, *218*, 154–163. [Google Scholar] [CrossRef]
19. Mara, D.; Sleigh, P.; Blumenthal, U.; Carr, R. Health risks in wastewater irrigation: Comparing estimates from quantitative microbial risk analyses and epidemiological studies. *J. Water Health* 2007, *5*, 39–50. [Google Scholar] [CrossRef] [PubMed]
20. Mara, D.; Kramer, A. The 2006 who guidelines for wastewater and greywater use in agriculture: A practical interpretation. In *Efficient Management of Wastewater*; Springer: Berlin, Germany, 2008; pp. 1–17. [Google Scholar]
21. WHO. *Guidelines for the Safe Use of Wastewater. Excreta and Greywater in Agriculture. Volume 2. Wastewater Use in Agriculture*; WHO Press: Geneve, Switzerland, 2006. [Google Scholar]
22. Ayers, R.; Wescott, D. *Water Quality for Agriuclture*; FAO: Rome, Italy, 1985; p. 174. [Google Scholar]
23. FAO. Wastewater Treatment and Use in Agriculture. Avaliable online: http://www.fao.org/docrep/T0551E/T0551E00.htm (accessed on 30 April 2017).
24. Environmental Protection Agency. *Guidelines for Water Reuse*; U.S. Environmental Protection Agency: Washington, DC, USA, 2004.
25. Environmental Protection Agency; U.S. Agency for International Development. *Guidelines for Water Reuse*; U.S. Environmental Protection Agency: Washington, DC, USA, 2012.
26. Wintgens, T.; Bixio, D.; Thoeye, C.; Jeffrey, P.; Hochstrat, R.; Melin, T. *Integrated Concepts for Reuse of Upgraded Wastewater*; AQUAREC: Aachen, Germany, 2006. [Google Scholar]
27. Winpenny, J.; Heinz, I.; Koo-Oshima, S.; Salgot, M.; Collado, J.; Hérnandez, F.; Torricelli, R. *Reutilización del Agua en Agricultura: Beneficios para Todos*; FAO: Rome, Italy, 2013; Volome 124. [Google Scholar]
28. Bixio, D.; Wintgens, T. *Water Reuse System Management Manual Aquarec*; Office for Official Publications of the European Communities, European Commission: Brussels, Belgium, 2006. [Google Scholar]
29. Silva, J.; Torres, P.; Madera, C. Reuso de aguas residuales domésticas en agricultura. Una revisión. *Agron. Colomb.* 2008, *26*, 347–359. [Google Scholar]
30. Becerra, C.; Lopes, A.; Vaz, I.; Silva, E.; Manaia, C.; Nunes, O. Wastewater reuse in irrigation: A microbiological perspective on implications in soil fertility and human and environmental health. *Environ. Int.* 2015, *75*, 117–135. [Google Scholar] [CrossRef] [PubMed]
31. United Nations World Water Assessment Programme. *The United Nations World Water Development Report 2017: Wastewater, The Untapped Resource*; UNESCO: Paris, France, 2017. [Google Scholar]
32. Banco Mundial. *Protección de la Calidad del Agua Subterránea. Guía Para Empresas de Agua, Autoridades Municipales y Agencias Ambientales*; Banco Mundial: Washington, DC, USA, 2002. [Google Scholar]
33. Pimentel, D.; Pimentel, M. *Food, Energy, and Society*; Taylor & Francis Group: Boca Raton, FL, USA, 2008. [Google Scholar]
34. Corcoran, E.; Nellemann, C.; Baker, E.; Bos, R.; Osborn, D.; Savelli, H. *Sick Water?: The Central Role of Wastewater Management in Sustainable Development: A Rapid Response Assessment*; Earthprint: Arendal, Norway, 2010. [Google Scholar]
35. FAO. *The State of Food Insecurity in the World 2015. Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress*; FAO: Rome, Italy, 2015. [Google Scholar]
36. Cruz, R. Medición del agua de riego. *Tecnicaña* 2009, *34*, 27–33. [Google Scholar]
37. Moscoso, J. Aspectos Técnicos de la Agricultura con Aguas Residuales. Availabe online: http://bvsper.paho.org/bvsacd/scan/019502.pdf (accessed on 25 September 2017).
38. Barreto, A.; Do Nascimento, J.; Medeiros, E.; Nóbrega, J.; Bezerra, J. Changes in chemical attributes of a fluvent cultivated with castor bean and irrigated with wastewater. *Revista Brasileira de Engenharia Agrícola e Ambiental* 2013, *17*, 480–486. [Google Scholar] [CrossRef]
39. Henze, M.; Comeau, Y. Wastewater characterization. In *Biological Wastewater Treatment: Principles, Modelling and Design*; IWA Publishing: London, UK, 2008; pp. 33–52. [Google Scholar]
40. Liu, Y.; Haynes, R. Origin, nature, and treatment of effluents from dairy and meat processing factories and the effects of their irrigation on the quality of agricultural soils. *Crit. Rev. Environ. Sci. Technol.* 2011, *41*, 1531–1599. [Google Scholar] [CrossRef]