CHAPTER-2

LITERATURE REVIEW

2.1 Reuse in Various Countries

In this chapter various sewage reuse practices adopted and studies conducted all over the world are reviewed

2.1.1 Water and wastewater: Treatment, recycle and reuse in India

(Kaul S N , Mahajan A. U and Nandy T., 1999)

The quantity of water used in India for domestic and industrial supply forms about 8.4% of total available water and this demand is expected to double by the year 2025. It is estimated that 31% of rural population and 77% of urban population in India has access to potable water supply Only 63% of the metropolitan population is provided with sewage connection and treatment system (Refer to Table 2.1). Less than 5% of the total wastewater generated from the municipalities is collected and only 2 percent is treated. Often construction of conventional sewage treatment plant requires huge capital cost. The municipalities and public health departments are short of funds, thereby leaving most of the domestic wastewater untreated To focus on industrial pollution the Government of India has identified 19 critically polluted areas and 17 industrial sub sectors in the country which are polluting The Central Pollution Board (CPCB) is the national apex body for assessment, monitoring and control of water pollution The executive responsibilities for enforcement of various pollution control acts and laws passed by Government of India are carried out through this board. Contrary to the belief, agriculture sector is a major source for this board. Contrary to the belief that agriculture sector is a major source of water pollution, it is going largely unattended Popular precipitators as well as regulatory institutions have focused upon urban and industrial pollution. The present water pollution status in the country justifies the urgent and direct need to look for improved treatment methods and to develop new treatment approaches. This will not only help in meeting expected norms set by regulatory agencies but also promote implementation of cleaner and energy-saving technologies and support treatment to an extent that the reclaimed wastewater can be recycled or reused.

Table 2.1 Status of Water Supply, Wastewater Collection and Treatment in Metropolitan Cities

Name of the City	Pop. Covered by Water Supply (%)	Pop. Covered by Sewerage system (%)	Treatment Plant		Mode of Disposal
			Level	Cap. (MLD)	
Mumbai	99	80	Primary	82 0	Creek & Sea
Delhi	96	75	Primary & Secondary	745 0	River Yamuna & Agricultural land
Kolkata	95	-	Primary & Secondary	-	River Kulti & Hoogly
Hyderabad	100	78	Primary & Secondary	140.0	Land
Ahmedabad	90	75	Primary & Secondary	382.0	River Sabarmati
Banglore	100	85	Primary	286.0	Vrushabhavathi Valley & Bellandur Tank
Kanpur	75	60	Secondary	160.0	River Ganga & Agricultural Land
Lucknow	100	-	-	-	-
Chennai	85	77	Secondary	-	Sea & Irrigation
Nagpur	75	66	Primary (Not in Operation)	45.4	Local Nalla & Agricultural land
Pune	78	53	Primary	90 0	River & Agricultural Land
Jaipur	80	-	-	-	Agricultural Land
Total	**93**	**63**		**1930.4**	

(Source: CPCB, Delhi, CUPS/30/1989-90)

2.1.2 Municipal wastewater increases crop yields in Arizona, USA

(Day A. D. and Cluff C. B., 1985)

BUCKEYE, Arizona, an agricultural community located about 48 km west of Phoenix in central Arizona, consists of about 7,290 ha of farmland The well water in this district is high in total soluble salts If used as the only source of irrigation water, some crops might not reach maximum potential yields. To dilute the salt concentration, the Buckeye Irrigation Company began blending treated municipal wastewater from the city of Phoenix with well water in 1962. The amount of wastewater used for irrigation has increased steadily since that date. Treated municipal wastewater can be used as a partial source of irrigation water and plant nutrients in the commercial production of cereal grains. In 1962, Day and team reported higher grain yields from cereal grains irrigated with wastewater than from cereal grains irrigated with pump water and no additional fertilizer Wastewater-nitrogen and fertilizer-nitrogen were equally effective in stimulating forage production (Bole and Bell, 1978). In 1958, Dye noted that sewage effluent from an activated sludge treatment plant contained more nitrogen(N), phosphorus (P), and potassium (K), the principal elements for plant growth, than irrigation water from wells. According to the findings by Day and others in 1972, irrigation with wastewater over extended periods did not decrease field crop yields or result in any major deleterious effects on agricultural soils Wheat (*Triticum aestivum L)* grain grown with wastewater contained more protein than when produced with well water and equivalent amounts of N, P, and K.

Sorghum (*Sorghum bicolor L*) grown with wastewater produced higher grain yields than with well water plus N, P, and K in amounts equal to those present in wastewater. Grain sorghum residue consisting of the stalks and un-harvested grain from lodged sorghum, is an inexpensive source of cattle feed during the fall and winter months. The amount of residue that sorghum will yield depends on the genotype, location, year and farming practices. The nutritional quality of sorghum residue changes with each crop and with the length of time since the last harvest reported that the protein content of sorghum residue may differ because of climate, soil, cultural practices and variety According to a study by Perry and Olson in 1975, the percentage of crude protein in grain-sorghum residues would meet the minimum beef cow requirements, particularly since the animal would selectively graze the most nutritious plant parts.

The objectives of the research reported in this article were: 1) to study the use of municipal wastewater as a source of irrigation water and plant nutrients in the commercial production of sorghum and grain and forage and 2) to study the influence of municipal wastewater on sorghum grain volume-weight The experiments were conducted near Buckeye, Arizona, USA in 1975 and 1976.

2.1.3 Wastewater irrigation for developing countries

(World Bank reports on health effects and technical solutions, 1992)

World Bank technical paper number 51 summarizes information on international practices of wastewater irrigation for agriculture and reviews its public heath and technological aspects. This report, published in 1991, is the sixth in a series being prepared by the Resource Recovery Project as part of a global effort to realize the goal of the United Nations International Drinking Water Supply and Sanitation Decade, which is to extend domestic and community water supply and sanitation services throughout the developing world during 1981 to 1990. The project objective is to encourage resource recovery as means of offsetting some of the costs of community sanitation.

The report states that the concept of land application and wastewater reuse has gone through a complete cycle during the past century "Starting with official blessing and enthusiastic initiation of land application and sewage farming projects in England, Europe and the United States, it soon became almost the sole method of disposing of municipal wastewater. In the early years of the twentieth century, however, projects were often ill-conceived, inadequately funded, and poorly regulated, and thus were eventually abandoned. Subsequently, the concept of reuse fell into disrepute. Today, wastewater reuse is becoming widely accepted once again, except that now it is based on more rational, scientific and engineering principles."

Wastewater irrigation can reduce local pollution in receiving waters, especially in arid areas. The use of municipal and industrial wastewater from sewered urban centers makes it possible to conserve limited water resources for economically beneficial agricultural irrigation projects Moreover, it enables farmers in such areas to expand irrigated acreage. Also, wastewater irrigation returns nutrients such as nitrogen, phosphorus, and potassium, to the soil that would be expensive to buy in fertilizer form

Preferred fruits are those normally washed or treated before consumption, such as citrus, olives and avocados. Low growing but erect plants may also be used, including table grapes and tomatoes grown on trellises, sweet corn, peppers and brinjal particularly if they are grown in the ridge-and-furrow system and not irrigated by sprinkler system The crops least suitable are those with a supine growth habit, such as squash, cucumbers, some tomato varieties, strawberries, peas, beans, root crops such as carrots and radishes (which are eaten raw), as well as asparagus, potatoes, beets and onions.

Studies have shown that pathogens in the soil and on crops can live sufficiently long enough to survive harvesting and marketing and reach the public consuming such crops. Agricultural workers in direct contact with the wastewater, irrigated soil and crops are more likely to be exposed.

Enteric pathogens, particularly viruses, can be transported over considerable distances in the form of aerosolized droplets resulting from sprinkler irrigated wastewater. The droplets can then be inhaled by workers or nearby populations.

2.1.4 Pilot plant for reclaimed wastewater reuse in nurseries in Italy

(Gori R and Lubello C., 2000)

Pistoia, the most important nursery area in Italy, specializes in production of woody ornamental plants. Groundwater resources are used for irrigation in competition with urban use, causing serious water shortage problem in summer. Treated municipal wastewater can be a good alternative source of water and fertilizer nutrients for ornamental plant production. During 1998, they carried out an experiment along with local corporate bodies to evaluate the effects of Pistoia's wastewater treatment plant (WWTP) effluent irrigation of the (Pistoia) area-compared with traditional well water irrigation-- on three container-grown species, each of them characterized by different growth habits Plants irrigated with the effluent, treated with UV irradiation in a disinfection pilot plant, showed better physiological and growth parameters than those irrigated with traditional well water.

2.1.5 Effluent reuse in southeast Florida, USA

(Bors Gary W., 1984)

Bors explains that users who seek fresh water for irrigation purposes must compete for the available shallow aquifer groundwater against higher public needs such as regional water supplies. Considering Florida's rapid population growth, such competition is stiff indeed.

Potential users of reclaimed wastewater-such as managers of golf courses and parks-have requested water management, health and environmental agencies to closely examine the feasibility of such reuse. Bors provides this explanation of the three modes of land application recognized by the State of Florida and the EPA. (1) slow rate irrigation, (2) overland flow and (3) high rate infiltration.

2.1.6 Optimizing crop production via wastewater irrigation in California, USA

(Pettygrove G. Stuart and Asano Takashi, 1984)

Land application of municipal wastewater is a well-established practice in California According to a California State Department of Health Services survey, in 1977 wastewater was reclaimed at over 200 treatment plants and was applied to more than 360 locations Much of the reclaimed municipal wastewater (57%) was used for irrigation of fodder, fiber, and seed crops (a use not requiring a high degree of treatment), and only 7% were used for irrigation of orchard, vine, and other food crops An important use (about 14%) was irrigation of golf courses, other turf grass, and landscaped areas. Apart from irrigation use, the survey showed that 14% of reclaimed municipal wastewater was applied for groundwater recharge, 5% for industrial use, and smaller amounts were used for other purposes.

2.1.7 Wastewater recycling in Muskegon County, Michigan, USA

(Pound Charles E., Demirjian Y A. and Waggy W. Henry, 1983).

Muskegon country is located in the western portion of Michigan along the shore of Lake Michigan. Wastewater services for communities lying in the southwest portion of the county are provided by the Metro Plant of the Muskegon County Wastewater Management System (WMS). Through interagency agreements, the Muskegon County Board of Public Works serves as agent for the WMS, which serves five cities, one village, five townships and portions of three others.

Wastewater treatment services are currently provided by the County on a regional basis by two facilities A combined domestic-industrial wastewater is received and treated at both facilities The most northerly facility is known as the Whitehall-Montague system and the most southerly is the Metro facility. The Whitehall system is designed for a capacity of 4.92 million litres per day (mld) and the Metro facility was designed for a capacity of 159 mld. This paper discusses the Metro facility, and reviews features and benefits that have been derived from recycling wastewater over the past ten years.

2.1.8 City Sewage

(Tarr Joel A., 1981)

During the last generation, there has been an increased interest in the disposal of wastewaters on the land. Because land treatment systems contribute to the reclamation and recycling requirements of P L 92-500 Federal Water Pollution Control Act Amendments of 1972), the United States Environmental Protection Agency (E.P.A.) recommends that they should be given preferential consideration as an alternative wastewater management technology In recent years, the focus has been on developing land treatment technology and improving methods of control. While there are several different methods of land treatment, this article is concerned with the approach that has historically been most utilized - sewage farming.

The use of human wastes directly on the land is actually an old practice in human history. In Europe and in Asia, it was used for centuries by many peoples, including the Romans, the Flemish, the Dutch, the Chinese, Japanese and Koreans Americans also made extensive use of human waste from cities in the 19th century to fertilize farms. Medical theory of the time saw no danger in the practice as long as the wastes were not allowed to putrefy: sanitarians argued that "in the open country [human excrement] is diluted, scattered by the winds, oxidized in the sun; vegetation incorporates its elements".

One of the first experiences with sewage farming took place in Great Britain, where several cities including Edinburgh began the practice in about 1800. The leading advocate of sewage farming in England was Sir Edwin Chadwick, the great British sanitary reformer. Chadwick believed that the sale of urban sewage to farmers would pay for the cost of maintaining capital intensive urban sewage systems. In 1865 the British Sewage of Towns Commission reported in favor of the land-disposal method, and till the beginning of twentieth century the British Local Government Board insisted upon land application. In addition, in the late 19th century, extensive sewage farms were developed by Paris, Berlin, and other European cities.

In the United States sanitarians recommended land application of sewage as early as 1850. As more and more cities constructed sewerage systems, they naturally turned to sewage farming (or "broad irrigation" as it was called) as a means of disposal. In the late 1970's, several New England institutions began using their sewage to grow crops, and in 1881, Pullman, Illinois, which had a separate sewage system, became the first municipality to use a sewage farm for sewage disposal

2.1.9 Enhancement of integrated water management and water reuse in Europe and the Middle East

(Lazarova V., Cirelli G , Jeffrey P , Salgot M , Icekson N., and Brissaud F., 2000)

Municipal wastewater reuse, reclamation and recycling are essential to the development of sound water and environment management practices. In arid and semi-arid regions, wastewater reuse is a vital component of their development ensuring alternative water resources, sustainability, and reduction of the environmental pollution and health protection. The purpose of this paper is to provide an overview of the role of wastewater reuse in the development of new integrated resource management strategy in Europe and the Middle East.

2.1.10 Water reuse from sewage effluent by irrigation: a perspective for Hawaii

(Lau L. S , 1979)

A resource management strategy to conserve some of the high quality but virtually fully exploited groundwater reserves is discussed Field test from 1971-75 demonstrated that sewage effluent can be applied as supplemental water for furrow irrigation of sugarcane without harming either the crop or the ground water quality; effluent has been used on golf courses. Economic and legal aspects of such water reuse have still to be resolved but it seems clear that scientifically and technologically the techniques proposed are ready for implementation.

2.1.11 Agricultural reuse in Israel

(Shelef, 1992)

Shelef described the experience and knowledge gained in wastewater reclamation for agricultural irrigation in Israel during 1960's to 1990's. Details of two reclamation projects were provided. Performance of multistage stabilization ponds for treatment of wastewater for agricultural reuse was reported earlier by Saqqaar and Pescod The pond system was able to achieve complete removal of helminth eggs was unable to meet the acceptable guidelines (1000 fecal coliforms per 100 ml) established by the WHO Improvement in the quality of reclaimed irrigation water after treatment was reported by Azov asd Shelef to occur in the transmission system and the storage reservoir. Field experiments were conducted to evaluate the reuse of secondary treated municipal wastewater for irrigation of edible corn crops using both on-surface and subsurface trickle irrigation Corn yields with reclaimed water were compared to yields achieved with freshwater trickle irrigation. In another study with trickle irrigation, Oron et al. reported that minimal soil surface and plant contamination were detected under subsurface trickle irrigation compared with spray irrigation.

2.1.12 Agricultural utilization in European countries

(Sastry C. A., Mohanrao G.J. and Mehta R.S., 1964)

The principal utilization on reclaimed water till recently has been in irrigation. European countries, particularly Germany, have made considerable use of such water. In 1939, the sewage from one fourth of the sewered population of Germany, including Berlin, Liepzig, and six or seven other German cities, was employed for irrigation. Among other European countries using sewage effluents for irrigation are Spain, Italy & France

Where chemical concentration permits and where health regulations pertaining to the type of crop grown are met, sewage effluent has been found by experience to be excellent for irrigation. Sewage effluent has also been shown to be an adequate medium for leaching of alkali soils or improvement of barren soils.

Sewage effluents from complete treatment plants have delivered water for irrigation with less bacterial pollution than is found in many irrigation ditches. The Phoenix Activated Sludge Plant effluent when chlorinated passed the United State Public Health Service (U S P H S) bacterial standards for drinking water When this chlorinated effluent was sold to the Roosevelt irrigation district, it netted $12.15 per ha-m profit above expenses involved.

2.2 Reuse of Wastewater - Case Studies

2.2.1 Monterey, California reclaimed wastewater safe for irrigation vegetable crops

(Trends and Potential & Successful Recycling programs, World Watch Institute, 1986)

Reclaimed municipal wastewater is as safe as potable well water for use in irrigating raw vegetable crops, according to a report just published by the Monterey (California, USA) Regional Water Pollution Control Agency. The 10-year, $7 million research project was conducted by Engineering-Science (ES) with the University of California along with federal, state and local agencies. "No virus was ever found in the samples of crops spray-irrigated with the two types of reclaimed municipal wastewater used in this study," said Bahman Sheikh, Project Manager for ES. "Level of naturally occurring bacteria on crops irrigated with both well and reclaimed water were equivalent," he added The cost of producing reclaimed water, beyond secondary treatment and excluding transmission costs, was $2836.28 per ha-m if a new water resource was to be developed for irrigation purposes The report recommended that the Monterey Regional Water Pollution Control Agency proceed with full-scale reclamation of 113.56 mld of effluent for use on 4049 ha of artichoke-growing areas around Castroville, California, USA to alleviate water shortage and seawater intrusion in local aquifers.

2.2.2 Reclaiming 810 ha with wastewater in Midland, Texas, USA

(Report on a wastewater reuse project in Midland, 1981)

A wastewater reuse project in Midland, Texas, USA has turned depleted acreage into productive crop-producing land. The project required permit changes to downgrade the existing 22.71 mld wastewater treatment plant from secondary to primary treatment, expanding primary treatment elements and total reuse of the effluent for irrigation The upgraded primary treatment plant has a capacity of 45 42 mld, and the irrigation system is designed to handle 68 13 mld. It serves more than 95 percent of Midland's 75,000 residents

Designed by engineers in Black & Veatch, the system currently provides irrigation of approximately 810 ha. Effluent is transported from the wastewater treatment plant in a 91.44 cm combination force main and pressure gravity flow system 25.6 km to the project site. It is stored in eight impoundment cells having 80.97 surface hectares and a capacity of 317.76 ha-m. The impoundment area provides detention treatment as well as storage.

The cropping systems are balanced in rotation to allow the application of all of the effluent with minimum irrigation return flow and complete utilization of the nitrogen and phosphorus materials in the water. Wheat production of 263.8 bushels per ha and cotton production of 6.175 bales per ha during the first year of operation were more than double the average dry land yield in the area.

2.2.3 Case Studies in southwest Florida and California, USA as well as in Mexico

(Riper Craig Van and Geselbracht, 1999)

The Manatee Country agricultural reuse project in southwest Florida, USA was designed to meet the challenge of sustaining water resources and an accepted standard of living in the face of ever-increasing development demands in coastal areas. Start up of a 3702 ha-m / year water reuse project that supplies agricultural needs in the Salinas Valley of California, USA faced a number of issues not encountered in urban irrigation projects. A pilot study of advanced primary treatment followed by filtration and disinfection, conducted in Mexico City, Mexico was found to meet World Health Organization requirements for agricultural reuse.

2.2.4 Water reclamation and reuse in the county of Maui, Hawaii

(English John N., 1976)

A 15 100 m^3/d activated sludge plant effluent was filtered and used for parkland irrigation in the County of Maui, Hawaii A potential savings of $350 000 per year by switching from the domestic supply to reclaimed water for use in the park was ensured Oxidation pond effluent after phosphorus removal was used for parkland and airport irrigation, and recreational lake purposes in Lancaster.

The irrigation with wastewater resulted in an increase in production of 11.3 bushels/ha, and design data indicated that an application rate of 305 mm/y was feasible. Experiences with irrigation in Central Israel were discussed. The requirements for large and distant land tracks were identified and recommendations included the use of the wastewater on industrial and fodder crops not used for human consumption An irrigation rate of 50 mm per week was suitable for production of these crops Secondary effluent was applied to a mountain chaparral ecosystem to determine the effects on vegetation types in the selection of species for greenbelt establishment. A field study of the effects of applying a simulated municipal effluent to a corn field was carried out on a tile-drained loam soil. The corn yield was maximized at 500 mm/y loading rate. Canary grass was an acceptable species for irrigation with wastewater because of its flood tolerance and fewer number of the cereal leaf beetle and fruitfly insect pests.

2.2.5 Water reuse plan advances in Northglenn, Colorado, USA

(Ridgeway James, 1981)

During the 1970's, the City of Northglenn, Colorado (population 32,000), USA faced a shortfall in its water supply, devised a water reuse plan, working out an arrangement with a local farmers' irrigation company called FRICO (i e.Farmers Reservoir and Irrigation Company), which had the right to divert certain area's water supply due to rights assigned to members' individual land holdings. Normally FRICO's members would draw water from the Standley Lake via a canal, the primary irrigation ditch Once the water was used, it was gone for good for all purposes

The proposed water reuse plan was to operate as follows (excerpted from Energy-Efficient Community Planning by James Ridgeway, 1979, JG Press Inc., Ennaus, PA, USA):

"Under the proposed plan, a portion of the water from Standley Lake would no longer flow directly to the farmers. Rather, the water would be piped first to the city of Northglenn for municipal use and then recycled for agricultural uses. Storm water and wastewater would be collected, treated, stored and given back to the farmers for irrigation purposes. About 60 percent of the water borrowed in this manner from the FRICO reservoir and used by the city could be returned. The other 40 percent would be obtained from deep wells and storm runoff. For the use of the water, Northglenn would pay FRICO 10 percent interest, payable in water, not money. If, for instance, the city borrowed 617ha-m of water, it would return to the farmers 617 ha-m plus 10 percent or 61.7 ha-m i.e., a total of 678.71 ha-m."

2.2.6 Water pollution abatement through re-use of municipal waste water in agricultural systems in Isfahan, Iran

(Sanai M. and Shayegan J , 1979)

Part of the secondary-treated municipal waste water, in Isfahan, Iran, had been used to irrigate a 5-hectare research plot where soil and plants act as a filter for the polluting load. Results showed that a nearly complete renovation of waste water take place without permanent damage to the ecosystem. Yield is increased without reduction in quality and the scheme appeared to be feasible for recycling waste water, given correct land management.

2.3 Wastewater Treatment and Application - Concepts, Methods & Techniques

2.3.1 New concepts and criteria for reuse of treated wastewater in agriculture

(Gupta I.C., 2001)

The quality of treated wastewater for its reuse in agriculture has been evaluated conventionally on the basis of pH, salinity, EC (Electrical Conductivity), total solids- inorganic, sodicity (sodium percentages or Sodium Absorption Ratio i.e SAR), major ions (i.e Na^+, Mg^{+2}, Ca^{+2}, Cl^-, SO_4^{-2}, HCO_3^-, CO_3^{-2}, NO_3^-), minor ions (B^{+3}, F^-, Li^+) and micro-toxicants Whereas salinity continues to be the most important parameter, criteria of Electrical Conductivity (EC) 3 0 dSm^{-1} (TDS 2100 mgl^{-1}) have been reported to range from 1 5 to 10.0 dSm^{-1} The parameter of sodium percentage is obsolete. Sodium absorption ratio has been modified depending upon EC, HCO_3^-/Ca^{+2} ratio and Mg^{+2}/Ca^{+2} ratio and criteria value of 10 has been recognized to range from 5 to 30 Although most of the major ions are regulated by EC and SAR, separate consideration of CO_3^{-2} and NO_3^- is necessary. New criteria have been proposed for B^{+3}, F^- and Li^+.

2.3.2 Computer-aided design of effluent irrigation

(Hu Xiandeng and Pigram John, 2001)

Effluent irrigation systems are engineering systems that have been identified as an attractive option for effluent disposal in Australia for environmental pollution control and resource reuse As engineering systems, they should be designed based on established engineering procedures. At the moment, the systems are designed mainly on the guidelines issued by individual states in Australia, which are general engineering practices. However, the guidelines are quite different in different states There are no generalized and commonly acceptable design procedures available for reference. This study reports a generic calculation model for effluent irrigation design, and a decision support system called Computer-Aided Design of Effluent (CAD-Effluent) that was developed based on the model The model can accommodate different methods of estimating sustainable effluent loading rates such as the methods specified in guidelines, simulation models that describe the pollutant transformation processes in soils, or other empirical methods The application of CAD-Effluent is demonstrated using Queensland guidelines and climate data from thirty-one locations.

2.3.3 Tree plantations -Safe recycle of wastewater

(Papadopol Chris S., 2001)

Recycling municipal wastewater poses increasingly serious challenges to communities Specialized fast-growing plantations that require water and nutrients provide an efficient, inexpensive way to recycle effluent outside the food chain. This ability is especially promising for some less developed regions, which have high epidemic rates. Scientists at the Ontario Forest Research Institute in Sault Ste Marie, Ontario, Canada developed a software package for operating this recycling system on the basis of weather and soil conditions. It allows daily irrigation with effluent of a hybrid poplar plantation with an amount of effluent corresponding to atmospheric demand for evapotranspiration (ETp) in a particular day, thus avoiding the risk of deep infiltration.

2.3.4 Hygienic assessment of the method of sewage spraying for agricultural irrigation

(Baubinas A K. and Vlodavets V. V , 1979)

Spray irrigation of sewage on agricultural land was a more effective treatment method than irrigation along furrows, achieving a 95.3 per cent decrease in 20-day BOD and 97 5 per cent removal of ammonia. Bacteria aerosols spread 250 m away using short-spray apparatus, but reached 450 and 600 m when medium or far spray apparatus was used. Pathogens causing intestinal infections were recovered from grass and the atmosphere up to 400 m from the site of spraying

2.4 Reuse of Wastewater - Issues pertaining to Plant Growth and Yield

2.4.1 Crops grown with municipal wastewater

(Day A D , Wilson J. R and Katterman F. R., 1984)

In the semiarid areas of the world, the use of municipal wastewater in agriculture had received attention because it is a source of both irrigation water and also plant nutrients A study by Day and group in 1975 reported that when wheat (*Triticum aestivum L*) was grown with wastewater, it contained more total protein than when it was grown with well water plus suggested amounts of nitrogen, phosphorus, and potassium. Another study by Reynolds and group in 1979 found that when alfalfa *(Medicago sativa L)* was grown on a wastewater treated site the alfalfa recovered more rapidly after cutting and produced more forage than did alfalfa grown with conventional culture. Yet two more studies by Day and group in 1979 and 1981 observed that on large fields from 1970 through 1977 barley *(Hordeum vulgare L.)* that had been irrigated with a pump water and wastewater mixture produced taller plants, more vegetative growth, and higher grain yields than barley irrigated with only pump water. Cotton (*Gossypium hirsutum L*) grown with a pump water-wastewater mixture produced more seed cotton and seed with a higher seed weight than did cotton irrigated with only pump water The primary reason suggested for the increases in growth in the preceding discussion of wastewater application to crops is one of greater available nutrients However, Alemu's study in 1976 found an extract in municipal wastewater that increased total chlorophyll retention in wheat leaf tissue. He concluded that the high yields of high protein plant products obtained from plants grown with wastewater may have resulted from cytokinin-like growth substances present in treated municipal wastewater On the other hand in 1980, Katterman and Day isolated a ureido adenosine chromaphore from municipal wastewater which exhibited a moderate cytokinin-like activity

The objectives of this research were (1) to study the effects of eitht irrigation and fertilizer treatments on the growth and yield of Bermuda grass (*Cynodon* *dactylon L.*) and (2) to study the ability of Bermuda grass to utilize the plant nutrients in municipal wastewater and the plant nutrients in commercial inorganic fertilizer.

2.4.2 Effluent irrigation of rye and ryegrass

(Overman Allen R. and Ku Hsiao-Ching, 1976)

The winter forage crops rye (Secale cereale) and ryegrass (Lolium multiflorum) were grown on Lakeland fine sand in Florida, USA under irrigation with secondary municipal effluent. Irrigation rates from 25 mm/week-100 mm/week were used. Three cuttings of forage were obtained over a 21-week growing period. Dry matter yields increased with irrigation rate, while dry matter percentage showed a decrease Nutrient uptake generally increased with application rate, while recovery efficiency of all elements measured decreases. Recoveries of 67% and 50% of applied nitrogen (N) occurred at 118 kg/ha and 215 240kg/ha for rye, and at 218 kg/ha and 347 kg/ha for ryegrass. The effluent was deficient in potassium (K) relative to other nutrients. An irrigation rate of 25 mm/week to 50 mm/week appears suitable for production of rye or ryegrass with effluent on well-drained sandy soils.

2.4.3 Effluent irrigation of pearl millet

(Overman Allen R , 1975)

The summer forage crop pearl millet [Pennisetum typhoides (Burm), Tiftlate variety, was grown on Lakeland fine sand in Florida, USA under irrigation with secondary municipal effluent. Irrigation rates from 50 mm/week to 200 mm/week were used. Two cuttings were obtained over a 25-week growing period. Dry matter content decreased with irrigation rate, while plant uptake of nutrients (except Fe) showed an increase. Recovery efficiency of all nutrients measured decreased with application rate. Adequate levels of nutrients for crop fertility were present in the effluent with the exception of K. An irrigation rate of 50 mm/week to 100 mm/week for pear millet on sandy soil appears quite suitable

2.4.4 Effluent irrigation of different frequencies

(Overman Allen R., 1979)

The summer crops sorghum x Sudan grass, Sorghum vulgare Pers. x Sorghum sudanses Stapf., corn silage, and corn grain, Zea mays L., were grown on Lakeland fine sand in Florida, USA under irrigation with secondary municipal effluent Irrigation rates of 50 mm/week to 200 mm/week were used. Yields and nutrient uptake increased with irrigation rate, while dry matter content and nutrient content remained relatively constant. Yields were lower than those of fertility studies. Split applications produced slightly higher nitrogen uptake over single applications for sorghum as compared to Sudan grass and corn silage at 150 mm/week to 200 mm/week. Both methods gave comparable uptake at 100 mm/week for all three crops.

2.4.5 Land application of municipal sewage wastewater in Canada: yield and chemical composition of forage crops

(Bole J. B. and Bell R. G., 1978)

Irrigation with sewage-lagoon effluent, at water utilization levels, was satisfactory under the conditions of soil, climate and wastewater quality found at Taber, Alberta, Canada. All the forage crops studied, except tall wheat grass, were capable of taking up at least 250 kg nitrogen per hectare, in the presence of sufficient water and nutrients Alfalfa was the most suitable crop because of its self-sufficiency for nitrogen and its high yields In water of higher nitrogen content, reed canary grass may be more suitable, because it can withstand flood conditions and high soil moisture.

2.4.6 Reclaimed sewage water: A hydroponic growth medium for plants

(Wallace A , Patel P M., Berry W. L. and Lunt O. R., 1978)

Crops of cucumber, tomato, lettuce and chrysanthemum, have been grown in flow culture with secondary sewage effluent as the nutrient source. Energy was saved because fertilizers were not necessary. Copper, zinc, manganese, iron, nickel and lead were removed from the water by the plants so that it could be used for other biologically-based processes where heavy metals might cause problems. Variable amounts of nitrates and phosphates were stripped from the water, and these amounts could be increased at the expense of crop production.

2.4.7 Effects of wastewater and sewage sludge on the growth and chemical composition of turf grass

(Palazzo A. J., 1978)

A greenhouse study was conducted to determine the effects of wastewater and sewage application on two turf grass mixtures Prior to seeding in silt loam, soil in some pots was amended with sludge and control posts received commercial fertilizer supplying nitrogen, phosphorus and potassium. All pots were dosed with 5 or 10 cm treated sewage Wastewater and sludge treatments increased yields and uptake of nutrients and trace metals, yields tended to be lower from pots that received sludge but not wastewater

2.5 Reuse of Wastewater – Issues pertaining to Land Application

2.5.1 Utilization of municipal wastewater and sludge on land

(Gleason III T L., Smith JR J. E. and Page A. L., 1984)

Land application of municipal wastewater effluents and sludges has been a low-cost treatment and disposal alternative for many communities throughout the world, and current practices have evolved from one-step catch-all operations into functional unit processes. The 1972 Clean Water Act in USA strongly discouraged direct discharge of wastewater to surface water and encouraged the consideration of land treatment In 1973, when researchers gathered at a workshop and reviewed the recycling of municipal wastewater treatment plant effluents and sludges on land, they expressed considerable uncertainty about the performance, cost-effectiveness, site management, and environment impacts of the then current land treatment technology. In the past decade, the research and development efforts prompted by the 1973 conference have clearly demonstrated the technological feasibility and economic soundness of land treatment for use with both effluents and sludges. The database established by this ongoing research has enabled the promulgation of sound regulations and guidance concerning land application at the federal level and in more than 20 states of USA.

2.5.2 Impact of sewage waste application on soil strata

(Jain C. K. and Ram Daya, 1997)

The objective of this study was to provide information on utilization of sewage waste for irrigation purposes and their impact on the soil strata. The characterization of sewage waste indicated that the waste can be used for irrigation purposes. The concentration of various constituents monitored are within normal range and do not constitute a limiting factor for irrigation use. The spatial distribution of total concentration of various constituents in the soil profile showed that most of constituents are retained within the top 60 - 75 cm and no substantial migration took place in the soil strata. The quality of ground water in the nearby area is quite normal and does not indicate any appreciable sign of contamination due to land application of sewage waste.

2.5.3 An experimental and simulation study of waste effluent filtration through soil

(Lo K V., 1975)

The effects of land application of treated sewage effluent on the chemical characteristics of the percolating water were investigated in a series of experiments designed to measure the nutrient adsorptive properties of selected soils, to study changes in wastewater composition under downward flow conditions and to determine permissible loading rates to avoid groundwater pollution. Mathematical modeling was also applied to the movement of wastewater in soil columns during infiltration and redistribution. Results indicated that all soils achieved 99 per cent phosphorus removal, and at the end of the 12-week test period, nitrogen levels in all percolates were below the United States recommended limit for drinking water

2.6 Reuse of Wastewater - Issues pertaining to Health

2.6.1 Public health considerations in wastewater and excreta re-use for agriculture

(Feachem Richard, McGarry Michael and Mara Dunean, 1978)

Water shortages are becoming an increasingly important problem in arid zones as well as in areas considered to have plentiful water resources. Growing population and industrialization coupled with the introduction of modern intensive agricultural techniques involving irrigation are causing increasingly heavy demands on water resources The re-use of municipal and industrial wastewater has become an attractive option for increasing water reserves in such areas. Re-use of wastewater for agricultural purposes may be particularly attractive, since this may allow for the expansion of intensive agriculture while preserving limited resources of good quality drinking water for the rapid urban development that is taking place in most of the regions of the world In addition to the amounts of water provided by wastewater re-use in agriculture, many agronomists see the advantage of using such water, since it is rich in organic content and can be expected in many cases to supply part or even all of the nitrogen required to fertilize the fields as well as to provide some of the other essential nutrients The direct agricultural application of human excreta (i.e. night soil) has been widely practiced in many areas of the world primarily for its fertilizer value.

However, in planning wastewater re-use high priority must be given to the public health considerations since wastewater carries a potentially dangerous load of pathogenic micro-organisms that can be infectious to man. Health criteria must be established in the early planning stages of any wastewater re-use programme so as to ensure that the benefits gained by additional water resources are not negated by unreasonable public health risks to agricultural workers and the public at large.

2.6.2 Health aspect of water reuse in California

(Crook James, 1978)

The activities of the State of California Department of Health in the USA pertaining to wastewater reclamation and reuse are considered The historical sequence of regulation development in California and the rationale for specific policies and standards deemed necessary to assure public health protection are described, as is the current status of reuse in terms of numbers of wastewater reclamation facilities, types of reuse, and quantities of wastewater reused. Also, a relatively poor record of sewage treatment plant reliability is documented. The potential for human illness or disease from chemical and biological contaminants associated with wastewater reclamation is presented, both from the standpoint of water quality and operational procedures. The health risks associated with direct reuse for potable purposes are presented, with emphasis on treatment, reliability, and potential chronic health effects attributable to trace organic constituents.

2.6.3 Health Considerations in Use of Tertiary Effluents

(Cooper Robert C., 1977)

Increasing interest in the unrestricted reuse of highly treated waste effluents has stimulated renewed concern about the public health aspects of water quality. Many questions are being raised concerning not only the efficacy of traditional water quality parameters but also about the need for increased understanding of contaminants such as asbestos and trace organic chemical compounds.

The public health significance of wastewater reuse must be considered in terms of the disease agent involved and the dose of the agent to a susceptible population. In many instances, we are woefully ignorant of the significance of certain agents and often whether or not a substance is in reality an agent.

2.7 Reuse of Wastewater - Quality Requirements for Irrigation with Sewage Water

(Bouwer Herman, and Idelovitch Emanuel, 1987)

Irrigation is an excellent use for sewage effluent because it is mostly water with nutrients. For small flows, the effluent can be used on special, well supervised "sewage farms," where forage, fiber, or seed crops are grown that can be irrigated with standard primary or secondary effluent Large-scale use of the effluent requires special treatment so that it meets the public health, agronomic, and aesthetic requirements for unrestricted use (no adverse effects on crops, soils, humans, and animals). Crops in the unrestricted - use category include those that are consumed raw or brought raw into the kitchen. Most state or government standards deal only with public health aspects, and prescribe the treatment processes or the quality parameters that the effluent must meet before it can be used to irrigate a certain category of crops. However, agronomic aspects related to crops and soils must also be taken into account Quality parameters to be considered include bacteria, viruses and other pathogens, total salt content and sodium absorption ratio of the water (soil as well as crop effects), nitrogen, phosphorus, chloride and chlorine, bicarbonate, heavy metals, boron and other trace elements, pH and synthetic organics (including pesticides)

Table 2.2 to Table 2.17 represent guidelines / standards / recommendations for quality of wastewater and concerned governing parameters pertaining to agricultural reuse.

Table 2.2 Recommended Water Quality Guidelines for Wastewater Use for Irrigation in India

Particulars (unit of concentration / magnitude)	Recommended max. / allowable value of parameter
TSS (mg/l)	200
TDS (mg/l)	2100
pH	5.5-9 0
Oil & Grease (mg/l)	10
BOD (5 days 20° C), mg/l	100
As (mg/l)	0.2
B (mg/l)	2
% Na	60
RSC (mg/l)	5
CN (mg/l)	0.2
Cl (mg/l)	600
SO_4 (mg/l)	1000
Alpha emitters micro Curie/ml	10^{-8}
Beta emitters micro Curie/ml	10^{-7}
Bioassay test	90% survival of fish after 96 hr in 100% effluent
Mn (mg/l)	2
Pesticides (mg/l)	
1. Benzene Hexachloride	10
2. Carboryl	10
3. DDT	10
4. Endosulfan	10
5. Diamethonate	450
6. Penitrothion	10
7. Malathion	10
8. Phorate	10

9. Methyl parathion	10
10. Phenthoate	10
11. Pyrethrums	10
12. Copper oxychloride	9600
13. Copper sulphate	50
14. Ziram	1000
15 Sulphur	30
16 Paraquat	2300
17. Proponil	7300
18. Nitrogen	780

(Source: Schedule-VI, issued in GSR, 422 (E), dated 19/05/1993, MOEF)

Table 2.3 Reclaimed Water Criteria in Japan

Parameter	Toilet flush water	Landscape irrigation	Ornamental lakes and streams
E.coli (count/100 ml)	<10	Not detected	Not detected
Combined chlorine residual (mg/l)	Retained	0.4	-
Total coliform (count/100ml)	-	-	-
Appearance	Not unpleasant	Not unpleasant	Not unpleasant
Turbidity (NTU)	-	-	<10
BOD (mg/l)	-	-	<10
Odour	Not unpleasant	Not unpleasant	Not unpleasant
PH	5.8-8.6	5.8-8 6	5 8-8.6
Colour	-	-	-

(Source: Manual of guidelines for water reuse, 1992, Environmental Protection Agency, Washington D.C., U.S.A.)

Table 2.4 Reclaimed Water Standards in Kuwait

Parameter	Irrigation of fodder and food crops not, eaten raw forest land	Irrigation of food crops eaten raw
Level of treatment	Advanced	Advanced
Suspended Solids i.e SS (mg/l)	10	10
BOD(mg/l)	10	10
COD(mg/l)	40	40
Chlorine residual (mg/l) after 12 hr at 20°C	1	1
Coliform bacteria (count/100ml)	10000	100

(Source: Manual of guidelines for water reuse, 1992, Environmental Protection Agency, Washington D C., U.S.A.)

Table 2.5 Reclaimed Water Standards for Unrestricted Irrigation in Saudi Arabia

Parameter	Maximum contaminant level	Parameter	Maximum contaminant level
BOD(mg/l)	10.0	Cyanide (mg/l)	0.05
TSS(mg/l)	10.0	Fluoride (mg/l)	2.0
pH	6-8 4	Iron (mg/l)	5.0
Coliform (count/100ml)	2.2	Lead (mg/l)	0.1
Turbidity (NTU)	1 0	Lithium (mg/l)	0.07
Aluminum (mg/l)	5.0	Manganese (mg/l)	0.2
Arsenic (mg/l)	0.1	Mercury (mg/l)	0.001
Beryllium (mg/l)	0 1	Molybdenum (mg/l)	0 01
Boron (mg/l)	0.5	Nickel (mg/l)	0 02
Cadmium (mg/l)	0.01	Nitrate (mg/l)	10.00
Chloride (mg/l)	280	Selenium (mg/l)	0.02
Chromium (mg/l)	0 1	Zinc (mg/l)	4.0
Cobalt (mg/l)	0 05	Oil and grease	Absent
Copper (mg/l)	0.4	Phenol (mg/l)	0 002

(Source: Manual of guidelines for water reuse, 1992, Environmental Protection Agency, Washington D.C., U.S.A.)

Table 2.6 Maximum Concentrations for Reclaimed Water Reused in Agriculture in Tunisia

Parameters	Maximum concentrations	Parameters	Maximum concentrations
PH	6.5-8.5	Cobalt (mg/l)	0.1
COD	90	Copper (mg/l)	0.5
BOD (mg/l)	30	Iron (mg/l)	5
Suspended matters	2000	Lead (mg/l)	1
Chloride (mg/l)	280	Manganese (mg/l)	0.5
Fluoride (mg/l)	3	Mercury (mg/l)	0.001
Chromium (mg/l)	0 1	Nickel (mg/l)	0.02

Halogenated hydrocarbons	0 001	Lead	0.2
Arsenic (mg/l)	0.1	Selenium (mg/l)	0 05
Boron (mg/l)	3	Zinc (mg/l)	5.0
Cadmium (mg/l)	0.01	Intestinal nematodes	<1/1
Arithmetic mean number of eggs*	<1		

* Intestinal nematodes (i e. pathogenic agents like Ascaris & *Trichuris* spp. and hookworms) measured in Arithmetic mean number of eggs per litre (during the irrigation period)

(Source: Manual of guidelines for water reuse, 1992, Environmental Protection Agency, Washington D.C., U.S.A)

Table 2.7 Guidelines for Interpretations of Water Quality for Irrigation

Potential Irrigation Problem	**Units**	**Degree of Restriction on Use**		
		None	**Slight to Moderate**	**Severe**
Salinity				
(affects crop water availability)[1]				
EC_w	dS/m	<0.7	0.7-3.0	>3.0
(or)				
TDS	mg/l	<450	450-2000	>2000
Infiltration				
(affects infiltration rate of water into the soil. Evaluate using EC_W and SAR together)[2]				
SAR=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 Icon Toxicity				
(affects sensitive crops)				
Sodium (Na)				
Surface irrigation	SAR	<3	3-9	>9
Sprinkler irrigation	me/l	<3	>3	
Chloride (Cl)				
Surface irrigation	me/l	<4	4-10	>10
Sprinkler irrigation	me/l	<3	>3	
Boron (B)	mg/l	<0 7	0.7-3.0	>3 0
Miscellaneous Effects				
(affects susceptible crops)				
Nitrogen (NO_3-N)[3]	mg/l	<5	5-30	>30
Bicarbonate (HCO_3)				
(overhead sprinkling only)	me/l	<1.5	1.5-8.5	>8.5
pH			Normal Range 6.5-8 4	

(Source: FAO, 1985)

1. ECw means Electrical conductivity in deciSiemens per metre at 25 C
2. SAR means Sodium Adsorption Ratio
3. NO3-N means Nitrate Nitrogen reported in terms of elemental Nitrogen

2.8 Composition of Secondary Treated Municipal Wastewater Effluents and Irrigation Water Quality Criteria

Parameter	Range	Irrigation water quality criteria
Total Dissolved Solids (TDS)	200 - 1300	<2000
Biochemical Oxygen Demand (BOD)	20 - 50	NA
Chemical Oxygen Demand (COD)	25 - 100	NA
Total nitrogen	10 - 30	<30
Ammonical nitrogen	0 1 - 25	NA
Nitrate nitrogen	1 - 20	NA
Total phosphorus	5 - 40	NA
Chloride	50 - 500	<350
Sodium	50 - 400	<70
Potassium	10 - 30	NA
Calcium	25 - 100	NA
Magnesium	10 - 50	NA
Boron	0.3 - 2 5	<3.0
Cadmium (μg/l)	5 - 220	10
Copper (μg/l)	5 - 50	200
Nickel (μg/l)	5 - 500	200
Lead (μg/l)	1 - 200	5000
Zinc (μg/l)	10 - 400	2000
Chromium (μg/l)	1 - 100	100
Mercury (μg/l)	2 - 10	NA
Molybdenum (μg/l)	1 - 20	10
Arsenic (μg/l)	5 - 20	100

All units in mg/l unless otherwise noted (μg/l)

(Source: National Research Council 1996, Use of reclaimed water and sludge in food crop production)

Table 2.9 Recommended Limits for Constituents in Reclaimed Water for Irrigation

Part-I

Constituent	Long term use* (mg/l)	Short term use** (mg/l)	Remarks
Aluminum	5.0	20	Can cause low productivity in acidic soils but soils with pH of 5.5 to 8 0 will precipitate the iron and eliminate the toxicity
Arsenic	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice
Beryllium	0.10	0.5	Toxicity to plants varies widely ranging from 5 mg/l for kale to 0.5 mg/l for bush beans
Boron	0 75	2.0	Essential for plant growth with optimum yields for many obtained at a few tenths of mg/l in nutrient solutions Toxic to many sensitive plants e.g., citrus at 1 mg/l. Usually sufficient quantities in reclaimed water to correct the soil deficiencies. Most grasses relatively tolerant at 2 0 to 10 mg/l
Cadmium	0 01	0 05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended.
Chromium	0.1	1.0	Not generally recognized as essential element. Conservative limits recommended due to lack of knowledge on toxicity to plants
Cobalt	0.05	5 0	Toxic to tomato plants at 0.1 mg/l in nutrient solution Tends to be inactivated by neutral and alkaline soils
Copper	0.2	5 0	Toxic to number of plants at 0 1 to 1.0 mg/l in nutrient solution
Fluoride	1.0	15.0	Inactivated by neutral and alkaline soils

Iron	5 0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations
Lithium	2.5	2.5	Tolerated by most crops at upto 5 mg/l, mobile in soil Toxic to citrus at low doses : recommended limit is 0.075 mg/l
Manganese	0.2	10.0	Toxic to number of crops at a few tenths to a low mg/l in acid soils
Molybdenum	0 01	0 05	Nontoxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soil with high level of molybdenum
Nickel	0.2	2 0	Toxic to number of plants at 0 5 to 1.0 mg/l; reduced toxicity at neutral or alkaline pH
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low level of added selenium
Tin, tungsten and titanium	-	-	Effective, excluded by plants, specific tolerance levels unknown
Vanadium	0 1	1.0	Toxic to many plants at relatively low concentrations
Zinc	2.0	10.0	Toxic to many plants at slightly varying concentrations, reduced toxicity at increased pH (6 or above) and in fine textured or organic soils

* For water used continuously on all soil
** For use upto 20 years on fine textured soils of pH 6.0 to 8.5

Short term use of wastewater irrigation is having more concentration, because the soil is exposed to irrigation for a short period It reflects less harmful effects on quality and quantity of agricultural produce due to supply of less quantum of wastewater compared to soil exposed to long term wastewater irrigation. The unplanned long term use of wastewater leads to soil sickness.

Part-II

Constituent	Recommended limit	Remarks
pH	6.0	Most effects of pH on plant growth are indirect
TDS	500-2000 mg/l	Below 500 mg/l no detrimental effects are usually noticed. Between 500 and 1000 mg/l TDS in irrigation water can affect sensitive plants. At 1000 to 2000 mg/l TDS levels can affect many crops and careful management practices should be followed. Above 2000 mg/l water can be used regularly only to tolerant plants on permissible soils
Free chlorine residual	<1 mg/l	

(Source. Manual of guidelines for water reuse, 1992, Environmental Protection Agency, Washington D C., U.S.A.)

Table 2.10 Guidelines for Irrigation Water Quality for Agricultural Use

Jurisdiction	Acceptable Water Quality
Canada (Ontario)	Irrigation water should be of such quality as to meet the objectives for swimming and bathing uses (water should not cause diseases; fecal coliforms less than 100 per 100 mL; total coliforms less than 1 000 per mL)
Canada (Alberta)	For vegetable crops, geometric means should not exceed 1000 total coliforms per 100 mL nor 200 fecal coliforms per 100 mL, nor exceed numbers in more than 20 percent of the samples, nor exceed 2 400 total coliforms per 100 mL on any given day

USA (California)	For field crops, the water should have at least the quality of primary effluent For irrigation of parks and other land with public access, the water shall be an adequately disinfected wastewater (median MPN of <23 total coliforms per 100 mL).
USA (Georgia)	Fecal coliform levels not exceed 10 000 per 100 mL over a 30-day period and not to exceed 40 000 per 100 mL in more than 5 of samples.
USA (Massachusetts)	Coliform bacteria not to exceed an average of 1 000 per 100 mL in a month, nor 2 400 per 100 mL in more than 20% of samples
USA (Minnesota)	Crops, vegetation and truck garden crop irrigation water not to exceed 5 000 total coliforms per 100 mL.
USA (Nebraska)	For agricultural irrigation, not to exceed geometric mean value of 10 000 total coliforms or 2 000 fecal coliforms per 100 mL. Not more than 20% of samples to exceed 20 000 total or 4 000 fecal coliform bacteria per 100 mL.
USA (North Carolina)	For fruits and vegetables, fecal coliforms shall not exceed a log mean of 1000 per 100 mL during a 30-day period, nor exceed 2000 per 100 mL in more than 20% of the samples.
World Health Organization	It was assumed that only a limited health risk would result from the unrestricted irrigation of agricultural crops with sewage effluents having a bacteriological quality of 100 coliform organisms per 100 mL. Primary treatment of sewage was considered satisfactory for the irrigation of crops not for direct human consumption; for irrigation of produce, primary and secondary treatment should be used, preferably followed by filtration or polishing and disinfection.

(Parson, 1975)

Table 2.11 Guidelines for Irrigation Water Quality

Item	Irrigation purpose	Exposed group	Fecal coliforms (no. / 100 ml)	Intestinal nematodes (no. / litre)
1	Sports fields, public parks, hotel lawns	Public	<200	<1
2	Crops likely to be eaten raw	Farm workers, consumers	<1000	<1
3	Crops like cereals, fodder, industrial crops and trees	Farm workers	No coliform standard recommended	<1
4	Localized irrigation of crops in item 3	None	Pre treatment determined by irrigation technology, but minimum is primary sedimentation	

(Source: WHO, 1989)

Table 2.12 Existing Standards Governing the Use of Renovated Water in Agriculture in California

Crops	Treatment process suggested
Orchards and vineyards	Primary effluent No spray irrigation No use of dropped fruit
Fodder fibre crops and seed crops	Primary effluent Surface or spray irrigation
Crops for human consumption that will be processed to kill pathogens	For surface irrigation, Primary effluent For spray irrigation, disinfected secondary effluent (no more than 23 coliform organisms per 100 ml)

(Source: WHO, 1973)

Crops	Treatment process suggested
Crops for human consumption in a raw state	For surface irrigation, no more than 2.2 coliform organisms per 100 ml For spray irrigation, disinfected, filtered wastewater with turbidity of 10 units is permitted, providing it has been treated by coagulation

(Source : WHO, 1973)

Table 2.13 Water Quality Acceptable to Soils

Sr. No.	Nature of soil	Crops to be grown	Permissible limit of electrical conductivity of water for safe irrigation (Micro-mhos/cm)
1.	Deep black cotton soils having a clay content more than 30%	Semi-tolerant Tolerant	1500 2000
2	Heavy textured soils having a clay content of 20-30%	Semi-tolerant Tolerant	2000 3000
3.	Medium textured soils having a clay content of 10-20 %	Semi-tolerant Tolerant	4000 6000
4.	Light textured soils having a clay content less than 10%	Semi-tolerant Tolerant	6000 8000

(Source: Birdie G S., 1998)

Table 2.14 Hydraulic Rating of Loadings

Sr. No.	Nature of soil	Hydraulic loadings (m^3/ ha / day)
1	Clayey	30-35
2	Clayey loam	40-50
3	Loam	60-80
4.	Sandy loam	90-100
5.	Sandy	120-135

(Source. Birdie G. S., 1998)

Table 2.15 Total Concentrations of Trace Elements typically found in Soils and Plants

Element	Soils (μg/g)			Plants (μg/g)		
	Common	Range		Normal		Toxic
		Low	High	Low	High	
Arsenic	6	0 1	40	0.1	5	--
Boron	10	2	100	30	75	>75
Cadmium	0.06	0 01	7	0.2	0.8	--
Chromium	100	5	3000	0.2	1	--
Cobalt	8	1	40	0.05	0.5	--
Copper	20	2	100	4	15	>20
Lead	10	2	200	0 1	10	--
Manganese	850	100	4000	15	100	--
Molybdenum	2	0.2	5	1	100	--
Nickel	40	10	1000	1		>50
Selenium	0.5	0 1	2	0.02	2	50-100
Vanadium	100	20	500	0.1	10	>10
Zinc	50	10	30	15	200	>200

(Source: National Environment Research Center, 1974, Cincinnati Ohio, U.S.A.)

Table 2.16 Maximum Tolerable Levels of Dietary Minerals for Domestic Livestock in Comparison with Levels in Forages

Element	Soil Plant Barrier	Level in Plant Foliage (mg/kg dry foliage)		Maximum Level Chronically Tolerated (mg/kg dry diet)		
		Normal	Phytotoxic	Cattle	Sheep	Chicken
As*	Yes	0 01-1	3-10	50	50	50
B	Yes	7-7 5	75	150	150	(150
Cd	Fails	0 01-1	5-700	0.5	0.5	0.5
Cr^{3+} **	Yes	0.1-1	20	3000	3000	3000
Co	Fails?	0.01-0 3	25-100	10	10	10
Cu	Yes	3-20	25-40	100	25	300
F	Yes?	1-5	-	40	60	200
Fe	Yes	30-300	-	1000	500	1000
Mn	?	15-150	400-2000	1000	1000	2000
Mo	Fails	0.1-3.0	100-10	10	20	
Ni	Yes	0.1-50	50-100	50	50	300
Pb	Yes	2-5	-	30	30	30
Se	Fails	0.1-2	100	2	2	
V	Yes?	0.1-1	10	50	50	10
Zn	Yes	15-150	500-1 500	500	300	1 000

Note. * inorganic and ** oxides

(Source: Manual for land application of treated municipal wastewater and sludge, 1989)

Table 2.17 Selection of Crop based on their Tolerance to Common Toxic Substances present in Wastewater

Influence parameter					
Salinity		Boron		Exchangeable Na	
Most Sensitive	Most Tolerant	Most Sensitive	Most Tolerant	Most Sensitive	Most Tolerant
Bean Carrot Onion Almond Apple Cherry Grape Lemon Mango Orange Peach Raspberry Strawberry	Barley Cotton Sugar beet Date palm Wheat - grass Bermuda - grass Alkali grass	Lemon Grapefruit Orange Peach Cherry Fig Grape Cowpea	Cotton Sorghum Alfalfa Beet, red Sugar beet	Deciduous fruits Nuts Bean, green Cotton Maize Peas Grapefruit Orange Peach Mug Groundnut (peanut) Gram Cowpeas	Alfalfa Barely Beet- garden Sugar beet Bermuda- grass Cotton Wheat - grass

(Source: FAO Irrigation and Drainage Paper 29 Rev. 1, 1985)