CHAPTER 2

REVIEW OF LITERATURE

2.1 HISTORY OF WASTEWATER REUSE FOR IRRIGATION

The earliest documented sewage irrigation was practiced at Bunzlau, Germany, in 1531. Reports show that, Edinburgh in Scotland had a sewage farm in 1650, Gennevillier in France in 1872 and Melbourne in Australia by 1897. In India, the first sewage farm was started in Bombay in 1877 followed by Madras in 1912 and Delhi in 1913.(Shuval, 1977; Dean and Lund, 1981 and Shuval et al., 1986a).

The interest in wastewater farming or land application was created by the advent of water carriage sewerage system. The main aim of land disposal is to prevent the pollution of rivers and waterways. Sewage irrigation declined with the development of biological methods of wastewater treatment. Eventually sewage farming was almost abandoned by 1912 in developed countries (Shuval et al., 1986a and Okun 1991).

A new thrust of scientific and engineering interest in wastewater reuse has developed after the World War II. The possibility of wastewater treatment and disposal through land application gained attention, as a method of combating water pollution and increasing the water availability through wastewater reuse as an alternate source of water particularly in water starved arid regions of developing countries (Pescod et al., 1986).
2.2 PRESENT STATUS OF WASTEWATER REUSE FOR IRRIGATION

The need to increase food production through irrigated agriculture has made wastewater irrigation as a fruitful proposition in the Near East Region, South and South East Asia, Latin America, United States and Israel (Arceivala, 1977; Hart and VanVuuren, 1977; Muller, 1977; Dean and Lund, 1981, Keyser, 1988 and Pitchai, 1991). In countries where wastewater reuse is practiced, details on volume of wastewater utilised for irrigation, area receiving wastewater and purposes for which they are utilised are presented in Table 2.1 (USEPA, 1981; Abu-Zeid, 1988; Bahri, 1988; Ertuna, 1988; Shende et al., 1988 and Pescod and Arar, 1988; Shuval, 1990).

India has also recognised the need for an alternate source of water for its agricultural uses and has identified recycling and reuse of wastewater as a thrust area for its water resources development as chartered in its Water Policy (National Water Policy Document, 1987).

International Organisations such as World Health Organization (WHO), Food and Agricultural Organization (FAO), International Reference Center for Waste Disposal (IRCWD) have recognised wastewater as an alternate resource for irrigation (WHO, 1973; Prost, 1983; IRCWD, 1985a,b; 1988 and WHO, 1989). An investigation carried out jointly by WHO and United Nations Development Program (UNDP) under the International Drinking Water Supply and Sanitation Decade has looked into the various aspects of wastewater irrigation in developing countries (Clark, et al., 1976 and Blumenthal, 1988). The health effects of wastewater irrigation have received lot of attention from the international bodies and a thorough study on the epidemiology of the wastewater irrigation and the direct evidence of disease outbreaks have failed to establish any direct ill effect due to wastewater reuse in irrigation, in developed countries where strict quality control on treatment of wastewater and choice of crop grown are regulated (Shuval, 1978; Fattal, 1980; Applebaum et al., 1984; Gunnerson et al., 1985; Fattal et al., 1986a,b, 1987; Shuval and Wax, 1988; Blumenthal et al., 1989 and Mara and
Table 2.1  Details on countries reusing wastewater for irrigation purposes

<table>
<thead>
<tr>
<th>Country</th>
<th>No.of sites</th>
<th>Volume Mm$^3$/yr.</th>
<th>Area Ha</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States of America</td>
<td>3,400</td>
<td>210</td>
<td>-</td>
<td>Non food crops, ornamental lakes, planned groundwater recharge</td>
</tr>
<tr>
<td>Israel</td>
<td>-</td>
<td>50</td>
<td>10,000</td>
<td>Cotton, citrus, field crops and fruits</td>
</tr>
<tr>
<td>India</td>
<td>200</td>
<td>365</td>
<td>73,000</td>
<td>Cereals, fodder, sugarcane and vegetables</td>
</tr>
<tr>
<td>Germany</td>
<td>-</td>
<td>100</td>
<td>25,000</td>
<td>Grains, sugar beet, potatoes and grass land</td>
</tr>
<tr>
<td>Mexico</td>
<td>-</td>
<td>1261</td>
<td>41,500</td>
<td>Grains and fodder</td>
</tr>
<tr>
<td>Chile</td>
<td>-</td>
<td>-</td>
<td>16,000</td>
<td>Vegetables</td>
</tr>
<tr>
<td>Peru</td>
<td>31</td>
<td>-</td>
<td>1,800</td>
<td>Vegetables</td>
</tr>
<tr>
<td>South Africa</td>
<td>-</td>
<td>-</td>
<td>1,200</td>
<td>Winter grazing, hay production, corn maize for silage</td>
</tr>
<tr>
<td>Egypt</td>
<td>3</td>
<td>-</td>
<td>7,260</td>
<td>Citrus, date palm maize, olive, beans, pecan nuts and pomegranates</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>3</td>
<td>100</td>
<td>4,000</td>
<td>Date palm, fruit trees (olive and citrus) vegetables, fodder, wheat and land scaping</td>
</tr>
<tr>
<td>Jordan</td>
<td>4</td>
<td>27.2</td>
<td>500,000</td>
<td>Date palm, apple, olive, popular, fodder and vegetables</td>
</tr>
<tr>
<td>Kuwait</td>
<td>-</td>
<td>47.5</td>
<td>1,600</td>
<td>Alfalfa, fodder, cereals, vegetables, and orchard</td>
</tr>
<tr>
<td>Libya</td>
<td>3</td>
<td>40.2</td>
<td>2,970</td>
<td>Fodder, vegetables, wind breaks, cereals</td>
</tr>
<tr>
<td>Tunisia</td>
<td>5</td>
<td>40</td>
<td>1,098</td>
<td>Citrus, forage, golf course irrigation</td>
</tr>
</tbody>
</table>

Cairncross, 1989). The results of these studies have been brought out as a guideline for wastewater use in agriculture (WHO, 1989).

### 2.3 REUSE OF WASTEWATER FOR IRRIGATION IN INDIA

In India, reuse of wastewater for irrigation known as "Sewage Farming" is practiced in 200 places with a total land under irrigation is reported to be 73,000 ha (Shende et al., 1988). Both raw i.e. untreated wastewater, treated wastewater and industrial effluents are being utilised for irrigation in India. A variety of crops are grown using wastewater ranging from cereals such as rice and wheat, industrial crops like sugarcane, besides fodder grass and vegetables. Irrigation methods followed are mainly flooding or furrow irrigation, modern and sophisticated methods like drip irrigation and sprinkler irrigation are not used (Sivanappan, 1975). The reported studies from India seem to point certain defects and faults in the wastewater utilisation practices such as lack of rational approach, judicious planning, design and operation of sewage farms (Sastry, 1975 and Shende et al., 1988).

National water policy of India has emphasised on the water recycling and reuse as an improvement on the existing strategies. Innovations based on strong scientific and technical knowledge are required to eliminate pollution of surface and ground water resources, to improve water quality and to step up recycling and reuse of water. It is also projected that food production will have to be raised from present 150 million tones to 240 million tones by 2000 A.D. The demand for drinking water and water for livestock have also to be met. Hence frontiers of knowledge need to be pushed forward in several directions, among this is included recycling and reuse of wastewater as a policy for effective and economical management of water resources in India (Tyagi et al., 1989).

In Tamilnadu, sewage farming was first established in Madras city, when the water carriage sewerage system was first commissioned in the city way back in 1912 (Nalini, 1990). The first farm established in Kasimedu was lost by sea erosion
and presently 4 sewage farms are in operation in the city growing fodder crops (Srinivasan, 1991), all these four sewage farms are in operation in the city till date (Daivamani, 1989). It is estimated that, 7,272 ha of paddy or 14,545 ha of dry irrigated crops could be grown ultimately when 160 mgd of wastewater is to be collected from the Madras city alone (Sivanappan, 1975). This estimate could be realised only by 2021, as per the master plan devised by the Madras Metropolitan Water Supply and Sewerage Board (M.M.W.S.S.B), when the entire city could get additional water supply and the wastewater generation will also increase. It is also stated that 40,000 ha of land could be brought under sewage irrigation if the wastewater collected from the state of Tamilnadu is utilised for irrigation.

2.4 TREATMENT OF WASTEWATER FOR IRRIGATION

Hazards to the health of the public is inherent in reuse of wastewater for irrigation. However, the potential benefits to the community may be substantial, provided the health risks are minimized. These include

a. Substitution of wastewater to meet irrigation demand, thus conserving better quality water for other uses, particularly potable supplies.

b. Extending irrigated areas to produce more crops.

c. Reduction in the cost associated with producing or importing fertilisers since wastewater effluent contain major plant nutrients and many trace elements essential for plant growth.

d. Reduction in the cost of water supply for irrigation, particularly where this is pumped from aquifers.
The principal benefit must be, of course, the greater availability of cheaper and perhaps better crops to improve the nutritional status and well-being of the population (Hillman, 1988).

2.4.1 Quality criteria and guidelines

Scientifically and socially acceptable wastewater reuse based on microbial guidelines were developed in the first instance by the California State Department of Public Health as early as 1918 and modified and made stricter in 1948. The California regulations has specified, if irrigation by wastewater is required, secondary treatment followed by coagulation, filtration and disinfection of effluent with a median coliform concentration of 2/100 ml is recommended for vegetables eaten raw. That was essentially the same standard required for drinking water (Crook, 1978). The fact is, that the California standard for vegetable eaten raw is technologically achievable but it is most expensive. Advanced and well managed wastewater treatment plants are required for this and hence for practical purposes this is not feasible for developing countries (Shuval, 1991). World Health Organisation has published the first international guidelines and health safeguards (WHO, 1973) and prepared a policy document in conjunction with United Nations Development Program for promoting wastewater irrigation in developing countries (Shuval, 1978; Blum and Feachem, 1985; Engleberg Report, 1985; Shuval et al., 1986a,b and Bouwer and Idelovitch, 1987). Table 2.2 provides the recommended microbiological quality guidelines for wastewater use in agriculture. Technical report on the health guidelines for use of wastewater in agriculture and aquaculture has reiterated these standards.

The proposal by WHO (WHO, 1989) is not acceptable to most European, North American countries and Israel (Shelef, 1991). The microbiological quality guidelines, allowing upto 1000 fecal coliform per 100 ml (geometric mean) for irrigation of crops likely to be eaten uncooked has been criticized by Shelef (1991). But most of the developing and less developed countries may adopt these guidelines (Vargas and Mara, 1987).
Table 2.2 Recommended Microbiological quality guidelines for wastewater use in agriculture

<table>
<thead>
<tr>
<th>Category</th>
<th>Reuse conditions</th>
<th>Exposed group</th>
<th>Intestinal nematodes (arithmetic mean no. of egg per l)</th>
<th>Faecal coliform (geometric mean no. per 100ml)</th>
<th>Wastewater treatment expected to achieved the required microbiological quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Irrigation of crops to be eaten uncooked, sports field public parks</td>
<td>Workers consumers public</td>
<td>&lt;1</td>
<td>&lt;1000</td>
<td>A series of stabilization ponds designed to achieve microbiological quality indicated or equivalent treatment</td>
</tr>
<tr>
<td>B</td>
<td>Irrigation of cereal crops, Industrial crops, fodder crops, pasture and trees</td>
<td>Workers</td>
<td>&lt;1</td>
<td>No Standards</td>
<td>Retention in stabilization ponds for 8-10 days or equivalent helminth and coliform removal</td>
</tr>
<tr>
<td>C</td>
<td>Localized irrigation of crops in category B if exposure of workers and the public does not occur</td>
<td>None</td>
<td>-</td>
<td>Not Applicable</td>
<td>Pretreatment as required by irrigation technology but not less than primary sedimentation</td>
</tr>
</tbody>
</table>

The chemical quality and trace element limits for wastewater reuse is adopted from FAO report on irrigation water quality guidance (FAO, 1979). Extensive reviews on the guidelines for wastewater reuse in agriculture and quality criteria in using sewage effluent for crop production have been reported by many researchers (Pescod and Alka, 1988; Bouwer and Idelovitch, 1987 and Arar, 1988).

2.4.2 Treatment methods

If wastewater can be effectively treated before it is used for agricultural irrigation, the negative health effects on sewage farm workers and to population living in the vicinity can be reduced to a greater extent.

Of the identifiable health effects associated with use of wastewater for irrigation, those of greatest concern for most developing countries are those caused by enteric helminths - Ascaris, Trichuris, hook worm and under certain circumstances, beef tapeworm. To lesser extent, enteric bacteria and viruses cause some acute problem, but these are generally of short duration. The viruses pose the lowest health hazard of the three groups (WHO, 1973). An optimal wastewater treatment system should therefore be able to remove all helminths, while lower degree of removal of bacteria and virus might be tolerated. In addition, the effluent should be clear and odour free. The wastewater treatment processes most effective in meeting the new WHO (1989) recommended guideline is the simple, robust and relatively low-cost stabilization pond system. Waste stabilisation ponds are usually the wastewater treatment method of choice in warm climates wherever land is available at reasonable cost (Mara, 1988). They should be arranged in a series of anaerobic, facultative and maturation ponds with overall hydraulic retention time of 10-50 days. The design depends on the temperature and quality of effluent required. Pond series can be readily designed to produce effluents that meet the Engleberg guidelines for both bacterial and helminth quality, these effluents are also low in BOD and suspended solids (Feachem et al., 1983). The effluent from such ponds, with proper operation will usually meet the
recommended microbial standard of the WHO. These effluents can be used for irrigating crops, including high-risk category vegetables and salad crops. Crops of medium risk (those not eaten raw) could be irrigated with the effluent from intermediate pond system. (WHO Technical Report Series No: 517, 1973).

2.4.3 Land application methods for wastewater reuse

Land disposal of wastewater that is land treatment is defined as the controlled application of wastewater on to the land surface to achieve a designed degree of treatment through natural physical, chemical and biological processes within the plant-soil-water matrix. The three major land treatment process are slow rate, rapid infiltration and overland flow systems (Bouwer and Chaney, 1978; Bouwer, 1980). However, subsurface system, wet lands and aquaculture were also included under land treatment methods. Land application of sludge, injection wells etc., are also other forms of treatment and disposal of sewage or industrial wastes (USEPA, 1981). Although, slow rate process, rapid infiltration and overland flow are considered as land disposal methods, these rely more on the plant-soil matrix to treat the wastewater.

2.4.3.1 Slow rate process

Slow rate land treatment is the application of wastewater to a vegetated land surface. The surface application technique include ridge and furrow and border strip flooding. Application by sprinklers can be from fixed risers or from moving systems such as central pivots or drip irrigation systems, even subsurface irrigation has been successfully tried. The slow rate process can be operated to achieve a number of objectives such as

a. Treatment of applied wastewater.
b. Economic return from use of water and nutrients to produce marketable crops (irrigation).
c. Water conservation by replacing potable water with treated effluent for irrigation.

The slow rate systems can be managed as an agricultural system where application rates are between 2 to 8 cm/week. Turf systems can also be considered as slow rate system where golf courses, parks and other turfed areas are irrigated (Mujeriego and Sala, 1991). Forest system, where forest trees are grown under wastewater irrigation is also a slow rate application process (Chabra, 1989; Das and Kaul, 1992).

2.4.3.2 Rapid infiltration process

In rapid infiltration process, most of the applied wastewater is allowed to percolate through the soil, and the treated effluent drains naturally into surface water or joins ground water (Bouwer and Rice, 1984; Bouwer, 1985). Moderate to highly permeable soils can also be used in rapid infiltration process by spreading in basins or by sprinkling, vegetation is not usually planned. Objectives of such systems are to treat the water to recharge ground water, recover the renovated water by wells or under drain for subsequent reuse, as the aquifer acts as temporary storage of renovated water. This system is otherwise called as soil-aquifers treatment or infiltration percolation (Bouwer, 1988). Recharge of sewage effluent has been successfully demonstrated in cretaceous chalk outcrop in England (Baxter and Edworthy, 1981 and Montgomery, 1988). Hundreds of these infiltration percolation process are operated for many years in U.S.A. It is now being tried in Mediterranean sea resorts in Europe (Brissaud et al., 1991), nevertheless these systems are not used for renovating wastewater in developing countries. The loading rate is around 100-120 m/year and vegetation or gravel layer in the basins do not offer any particular advantage and the best bottom condition was bare soil (Bouwer et al., 1980).
2.4.4.3 Overland flow

During early 1970's, only slow rate (irrigation) and rapid infiltration were in use for municipal wastewater treatment. Over the next 10 years, overland flow treatment has emerged as an effective treatment process for raw wastewater after screening as well as for primary and secondary effluents of urban origin (Crites, 1984) and for animal wastes (Grier et al., 1977).

In overland flow process, wastewater is supplied at the upper reaches of grass covered slope and allowed to flow over the vegetated surface to run off collection ditches. This system is best suited to sites having relatively impermeable soils. The objective of this process is to achieve secondary effluent quality when applying screened raw wastewater, primary effluent or treatment of pond effluent and to achieve high level of nitrogen, biochemical oxygen demand (BOD) and suspended solids (SS) removal. Mass discharge of BOD and TSS from overland flow system significantly increased during rain fall (Zirschky and Abernathy 1985). Design and operating guidelines for overland flow are reported by Smith (1982) based on his predictive model to find the viability of removal of organic matter from wastewater by this process. As per the study the design and operation of overland flow systems should be based on the application rate, slope length and application period rather than hydraulic loading.

2.4.4 Crop Selection

From the point of view of total dissolved salts, the relative salt tolerance limits of most agricultural crops are well known. The crops are classified as tolerant, moderately sensitive and sensitive groups based on their ability to withstand salinity. Similar tolerance groups have been classified based on exchangeable sodium capacity and Boron. (FAO 1985).
In using sewage effluents, crop selection is based on the public health hazards. Table 2.3 gives the suggested cropping pattern for crops irrigated with wastewater (Juwarkar, 1988).

Following are few observations emerged from sewage irrigation:

a. Forest trees probably offer greater opportunities than other ventures for effluent irrigation.

b. Irrigation of industrial crops not intended for human consumption offers an alternative to forest irrigation.

c. Forage crops are more suited to sewage irrigation than vegetables. It should be noted that feed with dried hay or pellets carry lower associated health risk due to pathogens (Kandiah 1988).

d. To eliminate some of the undesirable plant responses with sewage irrigation, effluents should be diluted with freshwater (Baier and Fryer 1973).

2.5 EFFECT OF WASTEWATER IRRIGATION ON SOIL

Effect on soil due to wastewater irrigation is of concern, and hence the long-term effects are to be investigated thoroughly. The effect due to prolonged wastewater applications have been carried out by number of researchers. These studies include investigations in laboratories as pot culture as well as field experiments. The irrigation methods used in these studies include sprinkler irrigation in developed countries to drip systems in semi-arid and arid regions of Middle east (Abdel- Ghaffer et al., 1988; Kalthem and Jamaan, 1988). But irrigation methods practiced in Asian and other third world countries are surface irrigation methods (Duron, 1988).
**Table 2.3 Suggested cropping pattern for irrigation with primary treated and secondary treated sewage effluents**

<table>
<thead>
<tr>
<th>Types of Sewage Effluent</th>
<th>Suggested Crops in order of Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary treated sewage (preferably diluted)</td>
<td>1. Forest and avenue trees, ornamental flowering shrubs</td>
</tr>
<tr>
<td></td>
<td>2. Industrial crops, e.g. cotton, jute, milling type sugar cane, tobacco</td>
</tr>
<tr>
<td></td>
<td>3. Essential oil bearing crops, e.g. citronella, mentha, lemon grass.</td>
</tr>
<tr>
<td></td>
<td>4. Crops raised exclusively for seed production.</td>
</tr>
<tr>
<td></td>
<td>5. Cereal and pulse crops, e.g. wheat, paddy, green gram, pigeon-pea, black gram, soyabean, jowar, bajara etc.</td>
</tr>
<tr>
<td></td>
<td>6. Oil seeds, e.g. linseed, til, castor, mustard, safflower, soyabean, groundnut etc.</td>
</tr>
<tr>
<td></td>
<td>7. Fruit crops, e.g. coconut, banana, citrus etc.</td>
</tr>
<tr>
<td></td>
<td>8. Vegetables exclusively cooked before eating and borne on the plant away from the soil, e.g. brinjal (eggplant, lady’s finger (okra), cucurbits, beans etc.</td>
</tr>
<tr>
<td></td>
<td>9. Fruit crops borne on the plant sufficiently far from the soil, e.g. guava, chickoo, grape, papaya and mango.</td>
</tr>
<tr>
<td>Secondary treated sewage</td>
<td>Crops under 1 to 9 and</td>
</tr>
<tr>
<td>Secondary treated and disinfected sewage</td>
<td>10. All types of crops including vegetable borne near the soil surface but consumed after cooking, fodder grasses etc.</td>
</tr>
<tr>
<td></td>
<td>11. All crops without restrictions.</td>
</tr>
</tbody>
</table>

Reference: Juwarkar (1988)
2.5.1 Soil-the living filter

During land treatment, soil and its associated ecosystem components act as a physico-bio-chemical reactor capable of treating or stabilizing the pollutants through degradation, absorption, precipitation and utilisation by crops (Kaul et al., 1989). In the modern day, the movement towards land disposal method seems to have started with Muskegon county, Michigan which decided to install a large disposal system. However, the classic land disposal experiment is, the Penn State Project called 'living filters' (Egeland, 1973). The living filter, i.e. an aerobic soil zone, provides tertiary treatment of wastewater. Organic matter is decomposed by bacteria, nutrients are removed by plants or soil. Suspended matter and color are removed as water percolates through the soil. Heavy metals are absorbed by organic matter and clay particles. Soil filtration will also remove virus, which will decompose into harmless proteins. After percolating through the soil, water is collected by drains and finally discharged into surface water (Chaiken et al., 1973). There are no doubts that land disposal is a feasible method of disposing, adequately treated wastewater if the soil structure, geology, ground water hydrology and climate of the area are favourable.

2.5.2 Changes in soil properties under wastewater application

Ramanathan et al. (1977) have observed that sewage or wastewater irrigation results in desirable soil characteristic from the point of plant growth. Subbiah and Ramanathan (1983 a,b) have observed that changes in soil properties and nutrient uptake are influenced by the soil texture. Jayaraman et al. (1983 a,b) have reported that continuous application of sewage, decreased the bulk density of soil due to increased organic matter addition. A number of studies have been carried out in various parts of the world to find the long term effects of wastewater irrigation on soils. As a general observation significant differences between soils irrigated with wastewater and fresh water have been found. Fertility content were also found to increase, the electrical conductivity, calcium, magnesium, sodium, potassium, nitrate and sulphate increased. Irrigation with wastewater also produced
higher concentration of these parameters except potassium (Lalitha 1992). Effluent irrigation has also increased the SAR and levels of chloride in the soil extract. Though statistically significant differences were found, irrigation with reclaimed water did not have any harmful effects on the soil. (Abdel-Ghaffer et al., 1988; Papadopoulos and Stylianoa, 1988 a,b; Gohil 1989 and Sheikh et al.,1990).

2.5.2.1 Physical properties

Jayaraman et al. (1983a) have reported that while the structural indices and water holding capacity of soil were increased the bulk density has decreased due to prolonged wastewater irrigation. Sewage irrigation irrespective of the depth and periods tend to improve the total and capillary porosity (Abdel-Ghaffar et al., 1988).

2.5.2.2 Chemical properties

The continuous supply of wastewater and/or sewage sludge is reported to decrease the soil pH (King and Morris, 1972; Malarvizhi, 1986). Decrease in pH is attributed to the nitrification of ammoniacal and organic nitrogen of wastewater. The soluble salt content is reported to increase in wastewater irrigated soils (Epstein et al., 1975 and 1976). Jayaraman (1981) did not observe any perceptible change in total soluble salt level due to sewage irrigation in 15 and 28 years of sewage irrigated fields. The cation exchange capacity of soils under wastewater irrigation was found to be within moderate ranges (Gupta et al., 1990 and Sahoo, 1991) and has been shown to increase moderately in soil due to sludge addition (Paulraj, 1988).
2.5.3 Fate of nutrients in soil

In wastewater irrigation, the primary concern is the presence of nitrogen and phosphorus. The nutrients applied are incorporated in soil and taken up by plants, the rest may leach below the profile and contaminate the ground water.

2.5.3.1 Nitrogen

Nitrogen removal mechanism in wastewater irrigation is through crop uptake, nitrification-denitrification, ammonia volatilization and storage in soil (Lance, 1975). Percolate nitrogen concentration less than 10 mg/l can be achieved if nitrogen loading rates are adjusted (USEPA, 1981). To expect high nitrogen removal, the following conditions are to be met.

a. High levels of organic matter in soil and/or wastewater.

b. High soil cation exchange -characteristic of fine-texture and organic soils.

c. Neutral to slightly alkaline soil pH.

d. Alternating saturated and unsaturated soil moisture conditions.

e. Warm temperature.

The literature survey points out that proper nitrogen and irrigation management will reduce NO$_3$ - N build up in ground water (Hergert, 1986).

In soils where wastewater is applied regularly, nitrification is normally rapid, except when temperature is very low. Thus ammonium in 3 inches of wastewater, containing 50 mg NH$_4$-N/l, equivalent to 34 lb. N/ac (38.1 kg N/ha), would be nitrified within one week. The quantity of N lost through denitrification may vary from 1% to more than 90% of that applied. In general, coarse-textured, well drained soils of low organic matter content have a low potential for denitrification. Sandy loam and loam soils have medium denitrification, where as silt loams, clay loams and clay have high potential for denitrification.
Denitrification can be correlated with frequency of irrigation. Hence better N utilisation efficiency (less denitrification) can be obtained by fewer irrigation (Broadbent and Reisenauer, 1984).

2.5.3.2 Phosphorus

Phosphorus is removed primarily by adsorption and precipitation (Enfield, 1975). Crop uptake account for phosphorus removal in the range of 20 to 60 kg/ha a yr. (18 lb. to 53 lb./ac per yr.), depending on crop and yield (USEPA, 1981). Phosphorus sorption depends on capacity of soil profile, amount of clay, aluminum, iron and soil pH. In general, fine textured soils have the highest phosphorus sorption capacity and coarse textured acidic or organic soils have lowest. Approximately 70 to 76% of phosphorus is reported to be removed from the wastewater added to soil column (Reynolds, 1982).

Assuming a P content of 10 mg/l, 186 lb./ac (208 kg/ha) of P$_2$O$_5$ is added to soil, this is considerably above the average fertilizer application rate for crops. This might lead to ground water or surface water contamination (Iskandar and Syer, 1980; Latterell et al., 1982). Because of many uncertainties and acceptable ground-water phosphate levels, P addition must be monitored frequently (Broadbent and Reisenauer, 1984).

2.5.4 Micro nutrient and heavy metals in soils

Build up of Cd, Zn, Cu, Ni, Mo, Se and Co in soils is a potentially serious hazard to food chain, however build up of Cd is much more serious to humans and animals. Elevated levels of Zn, Cu and Ni may decreases crop yields but crops exhibit little toxicity. High levels of Mo causes molybdenosis in ruminants (Webber, et al., 1980; Webber, 1984). Land application of effluents is unlikely to cause metal pollution problem because the concentration of heavy metals in the effluents of municipal origin is very low compared with effluents from industries or from sewage sludges. (Webber and Bole, 1978).
2.5.5 Pathogen survival in soils

The survival rates of pathogenic bacteria in soil normally vary from one day to several months. Many factors affect the survival of enteric bacteria in soil. Increased moisture content, cooler temperatures and higher organic matter content, tend to favour longer survival (Reddy et al., 1989), but extremely acidic and alkaline conditions, sunlight and antagonistic microflora are opposing factors of survival. Protozoa and helminths appear to survive as long as enteric bacteria in soil. Ascaris ova may remain viable longer (Gerba et al., 1975 and Burge and Marsh, 1978). Depending on type of soil, temperature, pH and moisture content, enterovirus survival has been reported from 25 to 170 days (Wellings et al., 1975).

Movement of pathogens in soil involves transport by insects, rodents, wind blown soil, overland run-off and percolation through soil profile to ground water (Frankenberger, 1984). Continuous application of wastewater could result in accumulation of pathogens at the soil surface (Gerba et al., 1975). The main factors that govern the transport of bacteria, ova of intestinal worms and cysts of protozoa through the soil matrix are by sedimentation and adsorption. Most studies show that bacteria are confined to upper few centimeters of soil and never reach ground water unless the soil has large cracks or channels.

Removal of virus through soil column by adsorption are shown in batch studies. It is evident that movement of virus in soil depends on pH, cation exchange capacity, surface ionic strength and flow rate of percolating effluent (Gerba, 1987). Wastewater application to soil appears to be very effective in pathogen immobilization and inactivation (USEPA, 1981). The best information currently available does not in fact indicate the existence of additional assessable risk of pathogen infection through wastewater irrigation (Lia et al., 1975; Gerba 1987 and Bertucci et al., 1987). A recent study by Asano and Sakaji (1990) and Asano et al. (1992) has conducted a risk analysis in wastewater reclamation and
reuse from the point of pathogenic infections and have suggested that management practices would play a role in reducing the risk.

2.6 WASTEWATER IRRIGATION AND CROP GROWTH

The crops like paddy, citrus fruits, salad vegetables like lettuce, industrial crops like sugarcane are reported to be grown in wastewater from various parts of the world. The reports indicate no loss of productivity under wastewater irrigation. The choice of crop mainly depends on the socio-economic development of the country. The WHO guidelines give a broad indication for the choice of crop to be grown and level of treatment required for growing crops under wastewater irrigation. It also recommends microbiological quality for wastewater use in agriculture (Table 2.2). The chemical quality guidelines specified by FAO is presented in Appendix 1, Table A1.1 (FAO, 1979 and WHO, 1989).

Based on current epidemiological evidences a bacterial guideline of 1000 faecal coliforms (geometric mean) per 100 ml for unrestricted irrigation of all crops is recommended (Engleberg report, 1985). The natural dieoff of pathogens in the field constitutes a valuable additional safety factor in reducing potential health hazard (Vargas et al., 1991).

The crop selection criteria under wastewater irrigation is regulated by governmental policies in most of the developed countries apart from crop tolerance to salts and specific ions, management requirements, uptake of nutrients, crop water use, economic value of the crop, climate and physical and chemical properties of soil (Pettygrove and Asano, 1984). Suggested cropping pattern for irrigation with primary treated and secondary treated sewage effluents under Indian conditions as reported by Juwarkar (1988) is presented in Table 2.3.

Almost all crops have been grown under wastewater irrigation, a general observation on the sewage grown crops is that they have abundant vegetative growth with delayed maturity, i.e. flowering, fruit formation and grain development
(Sastry, 1975) and this is attributed to the presence of excess nitrogen in wastewater. The optimum nutrient level in sewage could be 25 to 70 ppm of nitrogen and 9 to 30 ppm of phosphorous. The major advantage of growing crops under wastewater is reiterated in number of studies as the contribution of nutrients is significant for the crop besides the water. Hence the crops have shown a better yield under wastewater irrigation (Overman, 1975; Oron, 1986 and Nashikkar, 1989). In incidences of excess nutrient concentration, in wastewater, diluting them with surface or groundwater has also been practiced.

The fodder and forage crops are commonly grown with sewage irrigation. Studies have shown that fodder quality of maize and reed canary grass grown under treated municipal wastewater have more feed value and yield was reported to be 17 to 36% more (Marten et al., 1980). Fodder crops such as alfalfa are also found to tolerate flooding and more efficient in removing nutrients (Bell and Bole, 1978).

Experiments with paddy have shown that excess nutrient supplied by wastewater is not advisable hence mitigating agents like duck weeds were grown, these weeds also helped in purifying wastewater further (Kawahata and Tatusakawa, 1986).

2.6.1 Yield of crops grown in wastewater

Experiments have been conducted to find the effect of wastewater irrigation on the yield of crops. Pot culture studies, green house studies, microcosms, out door test boxes and lysimeters had been used to investigate yield of crops, apart from field plots. Experiments with cereals like wheat, maize, ragi paddy and pearl millet have been reported (Overman, 1975; Overman and Hsiao-Ching Ku, 1976; Overman et al., 1978). The yield of crops have always been higher than those grown with well water or with the addition of commercial fertilizers (Padi, 1990 and Rajesekaran, 1990).
Crops had also been grown for fodder and it is reported that fodder quality of waste water grown crops are better (Marten et al., 1980). The nutritional status of wheat hay and grain grown in wastewater, such as growth, fiber, acid soluble nucleotides, Protein and amino acids have also been analysed (Day et al., 1974, 1975 and 1982) and the quality was found to be superior. Studies on corn have shown significant silage and grain yield when grown in wastewater (Karlen et al., 1976). High quality forage was obtained under wastewater application both in lysimeter studies and field trials carried out by Webber et al., (1980) and Webber and Bole (1978). These experiments were carried out on mixed forage grasses in cold regions with sewage sludge. The reported results by Iskandar (1978) conducted in six out door test cells on cold region recorded higher yield than control boxes. In semi-arid zones of Cyprus, Krentos (1988) and Papadopoulos and Stylianou (1988) have found that the yield of crops of wheat, corn and cotton are encouraging. Duron (1988) reported of large scale wastewater irrigation in Mexico, crops grown are maize, bean, wheat, alfalfa, vegetables and fruits and high yields were obtained. Studies on cotton with trickle irrigation has resulted in high yield with out additional fertilizer (Bielorai et al., 1984; Oron, 1986, 1987; Oron and DeMalach, 1987 a,b and Oron et al., 1991).

In Saudi Arabia, wastewater is at present used in growing date palm, vegetables, fodder alfalfa, millet, sorghum and barley under sprinkler and drip irrigation without any reduction in yield (Kalthem and Jamaan, 1988). Similar study from Kuwait where pepper, onion and other crops are grown on experimental basis, also showed no loss in yield (Cobham and Johnson, 1988). Studies from Israel also reiterates the increase in yield of crops grown in wastewater. A series of investigations carried out on cotton, sugar beet and Rhodes grass grown in Israel have shown increased yield compared to yield from fresh water to which nitrogen fertilizers have been added. A reduction in sugar recovery has also been recorded in this study, similarly feed value of Rhodes grass was slightly less which was compensated by increase in yield.
A well documented study in yield of sugarcane grown under effluent irrigation is reported by Lau et al. (1980). Sugarcane was grown in field plots under diluted treated sewage effluent and ditch water. The study was carried out in 2 phases. In the first phase of the study a 6% increase in yield was recorded by applying effluent for 1 year out of 2 year crop cycle. When effluent was used at 50% dilution an increase of 11% in yield was obtained, but the juice quality was poor and a drop of 15% in juice content was recorded (Lau et al., 1972, 1974, 1977 and Young et al., 1974 and 1978).

A series of experiments conducted by Bole and Bell (1978) and Bole and Could (1985), on alfalfa, reed canary and bromegrass, wild rye and tall wheat grass showed increased yield under wastewater irrigation. Application of wastewater at 10 cm per week recorded twice the normal yield, while 20 cm per week application recorded thrice the yield. Burns et al. (1985) reported increased yield in Bermuda grass of alfalfa and reed canary grass, under wastewater application.

Sprinkler irrigation with wastewater were tried on corn, but, the grain yield were not significantly affected by irrigation level (Hergert, 1986). In the city of Isfahan, Iran, crops such as alfalfa and maize were grown under wastewater by sprinkler irrigation. Sewage treated by trickling filter method was also used for irrigating the crops and the yields were unaffected (Sanai and Shayegan, 1979). Muskegon wastewater are treated to secondary levels and used in spray irrigation for crops (Chaiken et al., 1973).

Industrial effluents were also shown to produce normal crop yield when diluted with fresh water and used for irrigation, Somasekar et al. (1984) had used textile, paper factory, automobile and textile and food processing effluents to find their effects on growth and seed germination in paddy. Raw effluents altered the physico-chemical properties of the treated soil and they were responsible for reduction in rate of germination of seed. Diluted effluents however showed favourable effects on seedling growth. Seed germination had also been studied
by Rajarajan (1978) in paddy and ragi. Long term effect of beet sugar factory effluent on continuous application revealed that, the crops alfalfa and sugarbeet did not record any reduction in yield, however maize showed only a limited success (Shayegan and Sanai, 1980).

2.6.2 Nutrient uptake by crops grown in wastewater

The increase in yield recorded under wastewater irrigation as discussed in the above section is obviously due to the presence of nutrients in wastewater. Considerable amount of N, P, K, Na, Ca, Mg, Cl and $\text{HCO}_3$ are present in wastewater (Burns et al., 1985). The crop removal of these elements, particularly N, P and K is the added benefit in using sewage or wastewater for irrigation.

Number of studies have been carried out to find the effect of the presence of N, P and K on the crop yield. The fertilizer contribution of wastewater have been compared with addition of commercial fertilizer to ground water or fresh water. In certain cases where the nutrient content of wastewater, when found to be present in excess of nutrient required by plants, dilution of wastewater by fresh water have been attempted (Lau et al., 1980 and Somasekar et al., 1984).

2.6.2.1 Nitrogen

The removal of nitrogen from wastewater by crops, the uptake of nitrogen and amount of nitrogen recovered have been studied with a great interest by researchers from all over the world. Among the crops nitrogen uptake by forage grasses were found to be more and the percentage nitrogen removed were as high as 66 to 79%. Sugar beet was found to remove all the nitrogen that was applied. In cotton crop half the total nitrogen in the plants were accumulated in its seeds (Feign et al., 1979). In crops like cotton grown on wastewater under drip irrigation there are encouraging evidences on the suitability but, the irrigation management was essential to prevent excessive vegetative growth (Feigin et al., 1980). The studies have shown that large saving of nitrogen fertilizer was possible in all cases,
and the hazards of nitrate leaching below root zone were also less. Management was an important tool for the control of nitrogen in effluent irrigated fields (Feigin et al., 1978; Feigin and Kipinis, 1980; Kipinis et al., 1981). In another study on corn grown in clay soil, the availability of nitrogen from treated sewage effluent was found to be somewhat lower than nitrogen incorporation into soil before seeding or planting, this incorporation is called "priming effect" (Feigin et al., 1980). No difference in N recovery and yield between sewage effluent and mineral solution (simulated sewage effluent) could be noticed (Feigin et al., 1984).

Sugarcane plants irrigated with diluted effluents showed leaching of nitrogen in drainage water when 50% and 100% sewage were used for sugarcane (Lau et al., 1980).

Experiments conducted in cold region in test cells in which a mixture of forage grasses were grown, have shown that the test cells which received highest wastewater of about 15 cm/week showed the highest yield. The amount of Nitrogen taken up by the plants were calculated from plant tissue analysis and yield data to summarize the nitrogen budget for the test cells. These values varied from 341 to 542 kg N per ha. Highest value obtained was from cell receiving more wastewater (Iskandar 1978). Similar results of nitrogen uptake have been reported by Day et al., (1974, 1975) in their pot-culture study on wheat grown in treated municipal wastewater.

Nitrogen cycling in land treatment systems for municipal sewage effluent is site specific and is conditioned by soil, vegetative cover, vegetation management, total nitrogen load and other various forms of nitrogen. Among vegetation, cropland areas provide better option and opportunities for removing nitrogen that is present in wastewater. Forage crops were found to be a better choice in utilizing nitrogen under wastewater irrigation (Hook and Kardos, 1977). As the nitrogen applied in excess might possibly contaminate the ground water, it is desirable that nitrogen in wastewater should be essentially recycled wherever feasible, since N
is an essential nutrient required for production of food and fiber. Its reuse also represent energy conservation (Broadbent and Reisenauer, 1984).

2.6.2.2 Phosphorus

Phosphorus being the other major nutrient for plant growth when supplied to plant through effluent irrigation, plants showed increased uptake of the element with increasing availability in wastewater (Burns et al., 1985 and Subbiah et al., 1976c). The land disposal of effluent aimed at effective removal of P could be achieved only if the loading rates are adjusted in such a way for the plants to utilise them (Robbins and Smith 1977). When different crops like corn, reed canary grass and hard wood trees were studied for their phosphorus removal efficiency, it was found that no site had leaching losses of >3% of the total phosphorus applied, even after 9 years of continuous operation (Kardos and Hook, 1976). A five-year study of wastewater irrigation in terms of phosphate management for Waukegun silt loam plots were compared with plots which received mineral fertilizers. The plots which received higher levels of phosphate showed leaching of the nutrient below 60 cm depth (Latterell et al., 1982).

2.6.2.3 Potassium

Potassium uptake by plants exceeds 90% when corn was grown in simulated sewage effluent. Measurement of exchangeable K indicates that if effluents low in K and high in Na are used for irrigation, supplemental K must be applied (Karlen et al., 1976). A study in the cold regions on forages have also shown that more K application is required than what is supplied by wastewater since wastewater normally contains less K (Palazzo, 1977). Tietjen (1977) has also observed that supplemental potassium is required to get better yield in oats in pot culture studies.

As a general observation, when nitrogen, phosphorus and potassium are supplied through wastewater, it is reported that crops showed high average yields
with high wastewater application rate. The crop removal efficiency of nutrients is highest with lower rates of wastewater application. Very high wastewater application rates will also lead to nitrogen leaching below root zone or phosphorus accumulation in soil (Clapp, 1977; Hook and Kardos, 1977 and Palazzo, 1977). However, potassium needs to be supplied by K fertilisation for sustained productivity.

2.6.2.4 Trace element uptake by plants

Many elements (e.g. Cu, Zn, Ni, Co, Mn, Fe etc.) are essential in small quantities for the growth of crops. At higher concentration, many of them become toxic to plants and animals. Some elements such as As, Cd, Pb and Hg do not have any known physiological function and are always considered as biologically harmful (Page and Chang, 1984). Among the trace elements found in wastewater B, Cd, Cu, Mo, Ni and Zn are considered to present a potentially serious hazard if they are introduced into cropland soils in an uncontrolled manner (USEPA, 1973). However, no universally accepted toxic threshold values for trace element concentration in soil or for mass additions to the soil have been established. It is also reported that toxicity hazards can be minimized by maintaining soil pH above 6.5. Most trace elements are retained as unavailable and insoluble compounds in soil in the above pH (USEPA, 1981).

The distribution of heavy metals applied via wastewater irrigation of reed canary grass, corn and forest tree species have been studied. The concentration of Cu, Zn, and Cd was not found to increase substantially over the time period tested (Sidle and Kardos, 1977). A study reported by Sidle et al., (1976) has found that uptake of heavy metals by corn silage from a normally fertilised soil was generally greater than from a similar soil which had been irrigated with wastewater during growing season for 11 years. Tree species were also reported to take less heavy metals (Sidle and Sopper, 1976). A study on uptake of heavy metals of cadmium and zinc under sludge irrigation has shown that the concentration of heavy metals in grain were less compared to plant tissues (Kirkham, 1975). In a
series of experiments reported by Giodano and Mortvedt (1975) and Giordana et al., (1976) the crop removal of Zn was only 5% of that contained in wastewater and Cr uptake was not affected by high availability of Cr applied through wastewater. Long term reuse of sewage effluents resulted in increased levels of heavy metals in effluent irrigated soils and their uptake by plants. However, it has been reported that no phytotoxic symptoms were observed in the plants (El-Nennah and El-Kobbia, 1983).

Iskandar (1978) reported movement of applied heavy metal to a depth of 15-30 cm through soil profile, under high wastewater application rates. It was thought to be due to drop in soil pH and heavy metal accumulation was confined to the top 15 cm of soil.

Stucky and Newsman (1977) from their greenhouse pot study concluded that increasing the rates of application of dried and anaerobically digested sewage sludge decreased the available amount of Mn, Zn, Ni and Cd to plants. Alfalfa and tall fescue were the crops studied in strip-mine spoils. Accumulation of Cu was not affected by application rates. No toxicity symptoms were observed during two year growth period.

Number of research reports on heavy metal uptake by plants and accumulation in plant tissues under sewage sludge application are available (Bingham et al., 1976; Singh and Narwal, 1984; Reddy and Dunn, 1983). General observations of these studies are that even at increased rate of sewage sludge application and concentration of metals in plant tissues were below the levels considered toxic to crop growth (Paulraj, 1988 and Jayaraman, 1981).

When wastewater effluents are used for crop irrigation, the concentration of trace elements in the water is not high enough to cause any short-term acute harmful effects (Rajamannar, 1982). A typical wastewater may be applied for almost 100 years before any trace-element accumulation in the soil may reach a currently proposed upper limit for trace-element soil deposition and the amounts
applied to soils of wastewater with typical trace-element concentration (Page and Chang, 1985).

**2.6.2.5 Infection by pathogens**

The health danger associated with applying pathogen-laden wastes to crop land is the potential route of contamination of food material with bacteria and protozoa and other parasitic organisms. Rudolf and associates (Rudolf et al., 1950) did an extensive literature survey on this subject and reported the same. With tomatoes they observed surface contamination, particularly on imperfect fruits with coliforms. They felt that if no faecal material were applied for 30 days before harvest, contamination was reduced to safe levels. *Salmonella* and *Shigella* were undetected on tomatoes 7 days after contamination (Rudolf et al., 1951a,c,d). Study on *Entamoeba histolytica* cysts on tomatoes and lettuce, showed that cysts were very sensitive to drying. (Rudolf et al., 1951b,c). Studies on *Ascaris* eggs, on lettuce showed that eggs are viable for at least a month, however, they did not develop into motile embryo stage (Rudolf et al., 1951e,f).

An excellent review on the pathogen survival in soil receiving wastes has been done by Morrison and Martin (1977). They have come out with some general criteria to reduce possible transmission of disease agents through wastewater irrigation. The health risk posed by effluent irrigation in a semi arid area of Portugal was reported by Vargas et al. (1991). The residual contamination found on lettuces, spray-irrigated with effluent from conventional trickling filter plant, initially indicated high levels of faecal indicator bacteria on lettuces. Decontaminating in the natural daylight for five days was sufficient to bring it to local market quality. In United States, the use of wastewater for irrigation of crops that are eaten raw is not common. At present, sewage farms in Paris apply raw wastewater for fruits and vegetable (not eaten raw) are approved by government with no reported health problems. (USEPA, 1981).
When wastewater is applied by sprinklers, the potential for pathogens to survive on the surface of a plant cannot be ignored. Sunlight is an effective disinfectant, killing pathogens. To protect livestock, grazing should not be allowed on pastures irrigated with wastewater for three to four days following irrigation. If it is recommended, then at least one week break should be allowed for primary treated effluent used for irrigation. For forages in cold regions, a longer resting period is recommended (Bell and Bole, 1976).

Larkin et al., (1976) investigated the persistence of virus on sewage irrigated vegetables. The virus was inoculated into sewage water used for irrigating lettuce. It is reported that virus has been shown to persist on lettuce and radish plants normally consumed raw, up to 36 days. Their conclusions had been refuted by Flaming (1976a,b) on his discussion on the above published report and has reported that no recorded instance of disease had occurred as a result of pathogens being taken up through food chain or indirectly consumed by humans.

Further, the general conclusion that may be drawn from the literature survey, on the pathogens survival on plants is that even under extreme situation i.e. when poor quality effluent is used for irrigation of food crops employing a highly contaminating irrigation method such as spray irrigation, the bactericidal effect of hot dry weather, with strong sunlight, is sufficient to decontaminate crops to ‘acceptable’ bacteriological levels within short periods of time. In countries where the background contamination of locally produced vegetables are high, then the adverse impact of wastewater irrigated vegetables on local consumer is minimal (Vargas and Mara, 1987). This investigation had been carried out in an area non endemic to helminths. However, effective removal of helminth through wastewater treatments such as stabilization ponds will be required. This study seems to indicate that the Engleberg guideline of 1000 faecal coliforms per 100 ml for unrestricted irrigation as too strict, especially in hot dry areas.
2.6.3 Harmful constituents in food chain through wastewater irrigation

Pathogen infection and trace element toxicity are two harmful effects feared to find its way into food chain while indiscriminately using wastewater or sludge in agriculture. Number of epidemiological studies conducted and reported worldwide have failed to establish any additional instances of pathogenic infection through wastewater grown food or fodder (Fredrick, 1984).

Entry of heavy metals through plants, bioaccumulation and ultimate entry into human system were also being investigated. Bray et al., (1985) studied trace element accumulation in tissues of goat fed with silage produced in sewage sludge containing high concentration of Cd and Zn. The presence of these metals in animal tissues and kidney were analysed. Results revealed that Cd and Zn were found to accumulate in these parts of the animal much below the critical levels, even less by an order of magnitude to cause any renal failure in the animals. Other studies reported on bio accumulation of heavy metals in food chain by Thronton and Abrahams (1983); Murphy and Spiegel (1982) and Cataldo et al., (1987) also did not report any alarming results in accumulation of heavy metals.

Studies on concentration of lead, cadmium, selenium and arsenic in milk of cows and buffaloes in city of Madras has failed to reveal any excess of these elements in milk (Krishnasamy, 1990a, b). From these reports it could be inferred that wastewater application for crops need not increase incidences of pathogenic infection or bioaccumulation of heavy metals in human food chain.

2.7 USE OF INDUSTRIAL EFFLUENTS FOR IRRIGATION

Unlike organised and systematic reuse of urban effluents, use of treated industrial effluent is not very common in developing countries. Literature reports that on industrial effluent reuse from food processing industries, pulp and paper industries, distilleries, sugar industries and dairy industries are more common in
India. The quality of effluent that has to be discharged on land for irrigation has been specified by Bureau of Indian Standards (IS: 3307-1977).

Land treatment is the application of effluents following secondary treatment on land by any one of the several available conventional irrigation methods. Treatment is provided by natural process as the effluent moves through the natural filter provided by the soil, plants and related ecosystem. Hence use of effluent irrigation when designed and operated well, acts as advanced tertiary treatment technique.

2.7.1 Pulp and paper industry effluent reuse for irrigation

Pulp and paper industry is one of the high water consuming industries. In India at present there are 57 mills producing about 7,70,000 tons of paper per annum. The production is likely to increase in near future. The volume of wastewater generated is to the tune of 360 cubic meter per ton of paper manufactured (Pandey and Carney, 1989).

Objectionable constituents present in the effluent are colour, high suspended solids (375-2490mg/l), BOD (160-1370mg/l) and COD (470-2940mg/l). The effluent violates BIS tolerance limits for discharging it into surface water bodies with respect to BOD, and SS. Some effluents violate tolerance limits for irrigation use with respect to dissolved solids and percentage sodium (Technical Digest, 1972; Alli, 1989). Laboratory studies on land disposal of pulp mill effluent have shown that effluents with pH value between 6.5 and 9 could be used successfully to grow crops. SAR value of 8 or less are said to be satisfactory except for clay soils, to avoid deflocculation (Blosser and Owens, 1964).

A study conducted on paper and pulp industry wastewater in India has shown that crop germination is affected due to application of undiluted effluents. The diluted effluents are reported to perform well. Paddy yield were better than black gram, tomatoes and two other crops included in this study (Rajannan and
Oblisamy, 1979). This finding is in concurrence with findings reported by Somasekar et al., (1984). Pushpavalli (1991) has studied the effect of growing sugarcane and paddy using treated effluents from paper and pulp industry situated in Erode in India. The yield of crops are reported to be high and no harmful effect on soils have been reported.

Keith and Stack (1984) have stated that full-scale land application of high strength wastewater can be successfully carried out. Intensive agricultural activity results in efficient utilization of effluent, which supplies rich nutrients.

2.7.2 Sugar Industry Effluent Use in Irrigation

Shayegen and Sanai (1980) studied the long-term effect of sugar beet processing industry, on soil. The nutritive elements are reported to be absorbed by plants. Salts such as Ca and Mg were filtered by top layer of the soil and the leachette ultimately recharging the groundwater is reported to be essentially purified.

The treatment methods proposed for treatment of wastewater form sugar industries are anaerobic/aerobic pretreatment followed by crop irrigation, this has been successfully demonstrated in Hawaii where irrigation through drip is practiced (Young et al., 1991).

Disposal of sugar industry effluent is being practiced in many factories in Uttarpradesh and Bihar states of India. It was observed that 99 % of suspended solids and 65% of BOD was removed in the process of land application. It is also observed that the treated effluents cause accumulation of sludge on the field (Pandey and Carney, 1989).

In India, there are more than 330 sugar mills of which about 50 are integrated sugar-cum distillery units, hence the combined effluents are treated and used for land application (Tare, 1989). The use of treated brewery effluents when
applied in uncontrolled and unorganised manner seems to impair the soil chemical and physical properties and also leading to reduction in yield as observed by Santhi, (1992).

2.7.3 Dairy effluent disposal on land

Use of dairy effluent for irrigation is just in its infancy in India, as this has not developed into a full fledged industry until recently. Earlier dairy industry was almost a domestic small scale practice. Even today there are very few large scale industries in India and most of them are located in and around large metropolitan cities of the country.

Mohanrao (1972) has studied the characteristics of dairy effluents with respect to BIS (Bureau of Indian Standards). It has been found that dairy wastewater used on land for irrigation would be violating the Indian Standards as the tolerance limits with reference to BOD, total solids and oil and grease will be exceeded. Hence treatment of dairy waste is necessary before disposing it in inland water bodies or used on land for irrigation. Minimum treatment will be sufficient if the effluent is to be used for irrigation (Khurody, 1972). It is also stated that dairies handling pastured milk and bottling them produce wastewater which could be directly used for irrigation particularly for fodder crop cultivation. Para grass and guinea grass are the suggested fodder to be grown under dairy effluents. It has been reported that slight traces of milk solids and detergents will not affect the irrigation quality of effluent (Rajagopalan, 1972). Case studies conducted in dairies disposing their wastewater on land for cultivation tend to show that irrigation is one of the best method of dairy effluent disposal. Wherever treatment facilities are unavailable, dilution of effluents with freshwater has been suggested.

In developed countries, reed canary grass (Adamczyk, 1977) and forest trees have been irrigated with dairy effluents (Russel et al., 1991).
Research on other industrial effluent with aqueous oil effluents have also been reported. Use of these oily wastewater for land disposal has created no perceivable changes in soils (Neal et al., 1977). Crops such as paddy and tree crops of mango etc. are reported to be grown successfully in Trichy in India (Ilangovan, 1989).

2.8 PROSPECTS OF WASTEWATER IRRIGATION IN FUTURE

The population in urban areas is growing rapidly. In 35 years time, the number of large cities will double and the population living in them will triple (Okun, 1991). While new sources of affordable potable water will likely to decrease or be unavailable, sources readily usable i.e. reclaimed wastewater will double in the near future. Hence, water reclamation will represent an ideal method of augmenting this increasingly scarce commodity (Sheikh, 1991). Direct potable reuse of reclaimed wastewater require dual distribution system and indirect non-potable reuse option such as urban landscape irrigation, golf course irrigation etc. are a few opportunities open to wastewater reuse in developed countries. (Okun, 1985). Reclamation and reuse of water through direct potable reuse does not seem to be economically viable to developing nations like India. However, reusing appropriately treated wastewater for agricultural use seems to be a logical option for near-term to mid-term planning.

The reuse of wastewater for irrigation seems the best opportunity available in India, where at present collection, treatment and disposal is carried out by municipal agencies, reuse of reclaimed wastewater also rests with them. However, industrial wastewater treatment is carried out by the concerned industry and using the effluent for irrigation is carried out by individual farmers. At this juncture, it is perhaps appropriate to forecast the future trends in wastewater reuse option for agricultural use.

In India, a steady progress is being made in supplying protected water supply to urban and rural population. It is reported that 80% of urban and 25%
of rural population has been covered (Venugopalan, 1988). On the industrial front, again development of industries will be generating 750 million cubic meter of wastewater. Hence the combined wastewater generation is expected to be 4400 million cubic meters per annum which needs to be disposed safely. It is estimated that 250,000 ha of land in the country could be irrigated for production of food, feed, fiber and fuel (Juwarkar, 1988). Treating them to a high degree of purity to meet quality requirement for disposal into surface water bodies under present conditions does not appear economically viable because of cost of treatment plant construction, operation maintenance, trained man power requirement and perhaps the most limiting factor appears to be energy requirement. An alternate method to this expensive method of wastewater treatment would be to reuse both municipal and industrial effluents of acceptable standards for irrigation purposes.

2.8.1 Delphi

"Project Delphi" is the name for a study of use of expert opinion that was conducted at the Rand Corporation. The technique employed was called "Delphi" method. Its objective was to obtain the most reliable consensus of opinion of a group of experts. The first experiment using this method was a classified military study (Dalkey and Helmer, 1963). Delphi method has then grown into most wide spread method for scenario building. It finds wide application in military forecasting, corporate planning, medical discipline, business forecasting to list a few. A comprehensive bibliography has been prepared by Pill (1970).

This technique tries to arrive at reasonable group consensus by iteration, but it is not just another kind of polling scheme. Opinion polling do not use iterative questioning with information feedback and do not present results in the form of group consensus (Smil, 1972). The delphi method has three distinct features that distinguishes it from other method such as committee interaction, anonymity, iteration with controlled feedback and statistical response (Martino, 1970; Salanick, 1971; Linstone and Turff, 1975 and Dickey and Watts, 1978).
The number of Delphi studies, which were only a few hundreds in 1969, has crossed the thousand mark in 1974 (Linstone and Turff, 1975). Today it is one of the most frequently used technique in long range planning and delphi has, to date is being used in the areas of technological forecasting more frequently than any other method.

Wills (1969) has conducted a Delphi study for British industries. It was employed for setting priorities for research and development projects and ultimately for national and corporate policy making.

Delphi study was applied to classroom exercise for decision making (Doyon et al., 1971). Another study by Teeling-Smith (1971), was on the medicine in the 1990's, created lot of public interest when it was published. This article describes step by step how a delphi forecast was done. Schneider (1972), had used policy delphi technique for a regional planning study. The study had an expert panel of 55 members, two rounds of the study indicated some promising directions in public participation in planning process. Urban planning concept in the design was studied using delphi by Skutsch and Schofer (1973), this delphi demonstrated meaningful, stable estimates of community goals and objectives.

Smill (1972) had conducted a Delphi study for the forecast on energy and environment. Currill (1970) had conducted it on six major UK companies in forecasting on future technologies, interview was used as a methodology for collecting data.

Delphi technique has found numerous applications in long range forecasting and scenario building. NuDs and Bottomley (1978) employed this technique to analyse economics of choice between sewage treatment works or sea out fall in order to dispose effluents from a European city.

Singg and Webb (1978) had also used Delphi methodology to assess goals and social impacts of a watershed project. This study was conducted for the
Cooper dam and reservoir project located in Texas U.S.A. Personal interview was employed for collecting data, it helped in identifying its goals and social impact in terms of selected criteria.

Delphi methodology has been used as a decision tool for larger urban planning studies also (Shefer and Stroumsa, 1981). Delphi method was found to be appropriate for formulating group value judgments. This study had large number of experts on the panel (191). This study was also conducted in two rounds. The aim was to find the competing utility functions in order to calculate street-lighting project planning in cities of Israel. Importance of Delphi in selecting indicators, key areas and benefits in housing schemes have been demonstrated for slum clearance board projects in Madras (Hemavathi Sekar and Anatharajan, 1993) and attempts have been made to use Delphi in wastewater reuse has also been carried out (Perasiriyan, 1993).

Other recent study, reporting the use of Delphi is a study on bridge condition rating and effects of improvement. This study was a part of an effort to develop guidelines for appraising bridge improvement needs (Satio et al., 1991). Economic assessment study using delphi methodology was adopted by Robinson (1991) to look at the road-funding situation in Canada.

The continued and wide use of this technique in technical, goal and policy forecasting has been demonstrated in the above studies. This technique seems to have worked well and with good response from panel members. It is also reported to have had significant advantages over other quantitative forecasting techniques.