WASTEWATER TREATMENT AND REUSE FOR IRRIGATION

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Contents

Summary

The technology and systems widely used today for wastewater treatment are not universally applicable. Historical perspective in public health, different habits, customs and practices and institutional agencies impose strict guidelines and are real constraints for worldwide adaptation. Doubts are increasingly being raised regarding the widely used water-borne sanitary wastewater system, in which expensively treated (potable) water is used to transport human waste to a remote location for treatment. In the process, the separated solids and the large quantities of effluents are disposed of directly into the ocean or rivers, and this in turn can lead to algal blooms and eutrophication. Furthermore, stringent environmental laws and public health regulations require extreme and costly measures, which are hardly affordable or practical. Within this context, a new approach has evolved in which wastewater is seen as a natural resource and part of the water cycle that can be reused for irrigation in agriculture, or other permissible usage. Thus, water supply and sanitation projects are being integrated so that the resulting effluents can augment freshwater supplies, while considering the impact of large scale and expanded use of effluents on the human and the natural environment. Overall practical experience in wastewater treatment and reuse as a sludge fertilizer and irrigation of crops are reviewed and discussed, as well as the associated short- and long-term human health-related hazards and benefits.

1. Introduction

The concept of community-wide systematic collection, treatment and disposal of wastewater evolved in the nineteenth century. The use of soil as a treatment medium and wastewater as a source of nutrients was advocated, in contrast to the customary discharge into water bodies. Since then, land application has been a common practice for disposing of municipal wastewater, and many large urban centers around the world have applied their wastewater to land for more than a century, including Paris, Berlin, and Melbourne. After the publication of the report of the first Royal Commission on Metropolitan Sewage Discharge and Sewerage Utilization in England in 1865, land treatment (now known as recycling and reuse) became one of the principal means of sewage disposal. Sewage farms were established in Edinburgh, London, Manchester, and other major cities of the United Kingdom. Widespread wastewater irrigation also became popular in other parts of Europe. Paris, for example, had a sewage farm as early as 1868, and by 1904 the great interception sewer of Paris had stopped discharging into the river Seine and all the dry weather wastewater flow was applied to sewage farms. The city of Berlin established its first sewage farm in 1876 and by 1910 Berlin was treating about 310 000 cubic meters of wastewater per day. Melbourne, Australia established its first large sewage farm—Werribbee Farm—in 1897, and grazed sheep and cattle on the grass grown in sewage-irrigated plots. Similarly, in 1904 planned sewage farming was established in Mexico City. In China at least 13 000 square kilometers of agricultural land is irrigated with untreated or partially treated wastewater from cities.

The early systems of land application were plagued with hydraulic and pollutant overloading and inexperienced operation, resulting in grave environmental pollution. Many of the early large irrigation and sewage farm projects in Europe were abandoned because urban development encroached upon the sewage farm areas. Bad odor and concern about transmission of diseases, improper application on land and discharge of raw sewage to nearby streams were also of great concern, leading to the cessation of irrigation with wastewater.

However, growing concern about the quality of rivers and water resources receiving vast quantities of wastewater has revived interest in wastewater reuse, both in industrialized and developing countries where there was an increasing demand for water resources. Countries in arid regions were particularly interested in utilizing wastewater for irrigation of crops. Furthermore, it was widely recognized that wastewater reuse in agricultur provides almost the only feasible, relatively low-cost method of sanitary disposal of municipal wastewater that minimizes pollution of waterways. In addition to its use for irrigation, reclaimed wastewater can be used for groundwater recharge and other beneficial reuses. These factors, coupled with rapid urban growth and the need to increase agricultural production, made sewage farms attractive to the agricultural community and municipal planners.

Application onto land can be an ecological friendly approach for the ultimate disposal of treated wastewater effluents. The growing vegetation is part of the land disposal system and it can be harvested or grazed by domestic animals. The natural physical, chemical and biological processes which dominate the soil profile remove the organic substances (BOD), suspended solids (SS) and soluble materials from the effluent during its passage through the root zone. These positive processes take place as long as the application rate does not exceed the natural self-purification capacity of the soil-plant system. When the capacity of the system is exceeded, organic substances, nutrients (nitrogen and phosphorus), pathogens and other substances percolating to groundwater or overflowing to surface watercourses can be hazardous.

After World War II, improved wastewater treatment technology resulted in a cost-effective land application alternative to surface discharge. Many of the difficulties resulting from pollutant overloading and public nuisance were remedied by properly treating the wastewater prior to land application. Many governments have recognized the importance of wastewater recycling through irrigation and have developed national wastewater reuse programmes as part of their water resources management policy. Such programmes have been established in Tunisia, Saudi Arabia, Israel, India, the Republic of South Africa, and some states in USA (e.g. California, Arizona, Florida), and their principles and technologies will be presented below.

2. Worldwide Sanitation Perspective

Waterborne epidemics plagued Europe in the nineteenth century and were the trigger for the increase in public health interest that prompted the beginning of municipal wastewater treatment worldwide. As a result, bacteria causing cholera and other deadly waterborne diseases were largely eradicated from industrial countries long before antibiotics and modern medicine were widely used. However, following the rapid growth of urban and industrial sectors in the twentieth century, and the associated discharge of effluents containing large quantities of pollutants, proper treatment and safe disposal of effluents are still a main concern of human society.

Nowadays, while water supply coverage is showing a significant improvement—with three-quarters of the population in developing nations having access to drinking water in 1994—half the world's population is still without adequate toilet facilities. In developing countries, in 1994, just about one third of the population had access to sanitation facilities, lagging well behind the goals of the UN International Drinking Water Supply and Sanitation Decade (1981–1990).

Lack of proper sanitation mostly affects the population of poor urban areas in which the crowded, unsanitary living conditions result in high incidence of diseases such as diarrhoea, typhoid, schistosomiasis and guinea worm. Lack of sanitation also leads to pollution of the local environment. Freshwater sources, such as lakes, rivers, oceans and groundwater, are all affected. This in turn adversely affects drinking water supply and the industries relying on good water resources, such as the tourism and fishing industry.

Excessive cost of sanitation projects is the major factor inhibiting their worldwide implementation. A large proportion of the cost of domestic wastewater systems is tied up in mains conveyance, pipes, pumping equipment and earthworks required to install large-scale sewerage systems, making it an expensive option. The high costs are often related to the treatment technologies, material and power used in the developed world. Such resources are often lacking in developing countries, and, if implemented, reflect inappropriate technologies, resulting in very limited sustainability.

Appropriate and sustainable technology means that the recipients or supporting organizations are: able to meet capital and ongoing costs associated with operation and maintenance (affordability); capable of carrying out the job; have people sufficiently skilled to operate the system, and the system selected is socially and culturally integrated, as well as in compliance with laws and prevailing standards.

To achieve sustainable conditions, safeguard public health and protect the environment, an integrated approach to water and waste management should be used. This includes integration of water supply, solid waste, storm water and wastewater—sectors which are normally treated separately even though, in many places, storm water, solid waste and sewage effluents get mixed and generate a combined flow. Domestic wastewater can be separated into black water (water originating from toilets and kitchens) and grey water (domestic wastewater from bathrooms and laundries), and community-scale sewage systems can apply separate treatment and effluent reuse.

3. Wastewater Composition and Characteristics

Domestic waste is flushed as sewage (comprising feces, urine and sullage) or nightsoil (feces and urine). Water-borne sewage flows in sewers draining the raw sewage from home to a wastewater treatment plant, from where the effluents are discharged to a recipient water body.

Raw sewage contains considerable concentrations of the phathogens associated with infectious diseases. Removal or significant reduction of these pathogens by microbial competitors and predators within biological treatment processes is a stringent requirement. Municipal wastewater is also a source of chemical pollutants that may affect human health. Tens of thousands of chemicals are being used routinely in manufacturing, in agricultural production, and in daily living. A fraction of them inadvertently find their way into municipal wastewater collection systems.

The numerous compounds can be identified using biological and chemical analytical tools and methods. In a sample of sewage taken to a laboratory, it is possible to analyze the composition of wastewater and to identify groups of compounds of special concern, as shown in Table 1.

Quality Parameter	**Raw Sewage**	**Treated Effluents**		
		Oxidation Ponds	**Mechanical System**	**Advanced Soil/Aquifer Treatment**
pH	7.3	8.4	7.9	8.2
Suspended Solids	380	83	8	0
Biological Oxygen Demand	430	37	8	0.5
Chemical Oxygen Demand	1050	203	55	9
Dissolved Organic Carbon	87	21	12	3
Soft and hard detergents	11	0.3	0.3	0.2
Total Nitrogen	62	19	13	3.6
Phosphorus	15	6	3	0.05
Boron	0.66	0.78	0.63	0.43
Chlorides	295	370	290	300
Total Dissolved Solids	1010	1150	900	940
Electrical conductivity	1820	1950	1600	1675
Cadmium	0.0029	0.0004	0.0003	0.0002
Copper	0.221	0.006	0.006	0.0004
Total coliforms	8.2	3.6	5.6	0
Fecal coliforms	7.2	2.9	5.1	0

Table 1. Typical quality of raw sewage and the resulting quality after various treatment processes (mg L^{-1}). pH values are unitless, electrical conductivity units are mmhos, while total and fecal coliform values are logarithms of their total numbers.

Adapted from Kanarek A., Aharoni A., Michail M. (1993). Municipal wastewater reuse via soil aquifer treatment for non-potable purposes. Water Science and Technology 27, 53-61.

One of the environmental effects of wastewater discharge which was first recognized was the depletion of oxygen in receiving waters. Thus, the biochemical oxygen demand (BOD) was introduced as a measure of the oxygen consumption caused by wastewater. The BOD test was an ingenious test for its time and is still in use to express the strength of sewage. BOD values of 400 to 800 mg L^{-1} are common, reflecting a release of 40 grams of BOD per person per day (see *Biochemical Oxygen Demand, Chemistry of Wastewater*).

4. Wastewater Treatment

Growing concern over toxicity and the long-term effects on the environment in general and the aquatic ecosystem in particular, has raised the priority of prevention of discharge of xenobiotic and potentially toxic compounds, organic pollutants and specific chemical compounds present in wastewater. About 90% of the added chemicals may be removed by biological treatment. However, complete removal of organic pollutants, not merely the readily biodegradable ones, is nowadays a requisite standard, coupled with reduction of specific chemical compounds and elimination of chronic as well as acute toxicity.

Treating sewage is therefore essential in order to reduce the spread of pathogens and the chemical pollution of natural water bodies, and, where possible, to generate safe effluent and or bio-solids for growing agricultural crops.

Many forms of treatment are available for sewage treatment in which there is flow and transformations of carbon, nitrogen, phosphorus and other nutrients, while the flow of organic waste is regulated so that the ability of nature to cycle these materials is not exceeded. Wastewater treatment plants are designed to feed a regulated waste flow along the natural cycle. Low cost systems especially suitable for hot climates are: waste stabilization ponds, aerated lagoons and oxidation ditches. These systems have an inherently good pathogen-removal performance compared to mechanically driven systems, such as trickling filters and activated sludge systems.

4.1. Biological Treatment

Biological treatment is the obvious choice to reduce the biochemical oxygen demand (BOD), as the pollutants giving rise to BOD are readily removed by biological treatment. The basis for aerobic biological treatment processes is that micro-organisms can rapidly oxidize organic pollutants into carbon dioxide and water. In nature, they do this either as a biofilm adhering to a surface or as freely motile micro-organisms, suspended in water. The biological treatment processes mimic these natural processes. Trickling filters, where micro-organisms grow as a biofilm, were introduced in the 1890s, while the activated sludge process, where bacteria grow in suspension, came in 1914.

4.1.1 Wastewater Treatment Process

Raw wastewater undergoes biological treatment processes of varying kinds, ranging from oxidation ponds, aerated lagoons and activated sludge, followed by chemical and physical treatments to generate effluents of various degrees of purification, as shown in Tables 1 and 2.

4.1.2 Preliminary Treatment

Raw sewage entering a treatment plant is normally screened to remove debris and other solids. The screens may be raked manually or mechanically and where necessary, when the grit content is too high, grit-removal channels are also provided.

Treatment Process	BOD	Chemical Oxygen Demand	Suspended Solids	Total nitrogen	Phosphorus as phosphates
Raw sewage	430	1050	380	50–80	15–25
Activated sludge	15–25	40–80	0–20	20–60	6–15
Activated sludge+filtration	5–10	30–70	5–10	5–15	4–12
Activated sludge + filtration + granulated carbon	1	5–15	3	0–15	4–12
Activated sludge + chemical treatment	5–10	40–70	5	0–15	1–2
Activated sludge + chemical treatment + filtration	5	30–60	1	15–30	0.1–1
Activated sludge + chemical treatment + filtration + N removal	5	30–60	1	2–10	0.1–1
Activated sludge + chemical treatment + filtration + N removal + granulated carbon	1	1–15	1	2–10	0.1–1

Table 2. Quality parameters of treated effluents using various treatment processes (mg L^{-1})

4.1.3 Primary Sedimentation: Anaerobic Digestion

After the pre-treatment to remove grit and debris, the wastewater may be diverted to small ponds for the first stage of treatment, known as Primary Treatment. The ponds act as biological reactors, under anaerobic conditions (in the absence of oxygen) for decomposition of organic material and generation of methane gas. In large treatment plants, the methane is collected and used for generation of electrical power or heating. Anaerobic ponds have hydraulic retention times of 1 to 4 days and a design depth of 2 to 4 meters. The volumetric loading design is in the range of 250 g m^{-3} of BOD per day. The ponds accumulate sludge at about 0.03 to 0.04 cubic meters per person per year and will require desludging every 3 to 5 years.

4.1.4 Secondary Treatment: Biological Oxidation

Anaerobic and aerobic biological processes are often used in series for complete removal of pollutants. Aerobic treatment may be achieved in many different systems and configurations. Secondary treatment systems based on the activated sludge process are mainly employed in municipalities and big cities where land for construction of wastewater treatment plants is limited and expensive. In medium and small towns appropriate technologies are usually employed due to shortage of funds, energy and skilled operational personnel. In rural area, land is usually not a limiting factor and treatment plants based on oxidation ponds can be built at much lower capital, operational and maintenance costs than mechanical secondary treatment plants of the same capacity.

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Bibliography

Abeliovich A. (1982). Biological equilibrium in a wastewater reservoir. *Water Research* **16**, 1135-1138. [Description of the fundamental biological degradation processes and transformation of elements which take place in the wastewater impounding body].

Chang A.C., Page A.L., Asano T. (1995). *Developing Human Health Related Chemical Guidelines For Reclaimed Wastewater And Sewage Sludge Applications In Agriculture*, 185 pp. Geneva, Switzerland: World Health Organization [An overview and practical guidelines for reuse of wastewater and sewage sludge, to reduce contamination of the environment and human health risks].

Feachem R.G., Bradley D.J., Garelick H., Mara D.D. (1983). *Sanitation and Disease: Health Aspects of Excreta and Wastewater Mangement*, 530 pp. Chichester, UK: John Wiley and Sons. [Health implications of water borne diseases and health benefits of appropriate sanitation and wastewater management].

Idelovitch E. (1978). Wastewater reuse by biological-chemical treatment and groundwater recharge. *Journal - Water Pollution Control Federation* **50**, 2723-2740. [Description of advanced technology for further purification of wastewater and production of high quality effluents for safe use].

Juanico M., Dor I. (Editors). (1999). *Reservoirs for Wastewater Storage and Reuse: Ecology, Performance and Engineering Design*, 394 pp. Berlin, Germany: Springer Verlag. [A compilation of recent works on the various biological and technical aspects related to wastewater treatment and reuse, including experience gained by various countries].

Selbst N. (1980). Economic, social and administrative considerations in the use of wastewater. *Water Quality Management Under Conditions of Scarcity: Israel as a Case Study*, (ed. H.I. Shuval), 243-269. New York: Academic Press. [Economic and social impacts of wastewater treatment and reuse in arid and semi arid regions, where water resources are scarce].

Shevah Y., Waldman M. (1999). Reservoirs for wastewater storage and reuse: research and development policy. *Reservoirs for Wastewater Storage and Reuse: Ecology, Performance and Engineering Design*, (eds. M. Juanico I. Dor), 3-11. Berlin, Germany: Springer Verlag. [Scientific background and supporting research for large scale application of innovative wastewater treatment and reuse].

Shuval H.I. (1990). *Wastewater Irrrigation in Developing Countries – Health Effects and Technical Solutions*, 74 pp. Washington, DC, USA: World Bank Tech. Paper No. 51, UNDP–World Bank wastewater and sanitation discussion paper series. [Consideration and implications of reuse of wastewater for irrigation in developing countries, prepared for use by the World Bank and UNDP].

USEPA (1992). *Guidelines for Water Reuse*, 247 pp. Washington, DC, USA: US EPA. [Practical guidelines for reuse of wastewater and sewage sludge under the US context].

World Health Orgainization (1989). *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture*, 74 pp. Geneva, Switzerland: Report of the a WHO Scientific Group, WHO Technical Report Series 778. [Health implications and recommendations for reuse of wastewater for irrigation and fish ponds by the World Health Organisation].

Biographical Sketch

Dr. Yehuda Shevah is expert in Water Resources Development, with a special interest in wastewater treatment and reuse technologies. He is a pioneer and promoter of combined wastwater treatment and reuse systems, contributing to the development of cost effective water resources for use in irrigation and other non-potable usages in arid and semi-arid regions, where water scarcity is a real constraint to social and economic devlopment. As a consultant, he is also engaged in strategic planning, project management and providing expertise on water and wastewater treatment and environmental studies, in respect of drinking water development, irrigation, human waste disposal and environment. He authored and co-authored numerous peer review articles and technical reports.

Combining an academic career with field experience, he has contributed to interdisciplinary and multinational research programmes as a member of various advisory/working groups and as a consultant to policy makers, international development agencies and governments, including the Word Bank, EU, and Israel's Ministry of Science and Ministry of Infrastructures. He was project director and team leader of water resources development projects and related environmental impact evaluation, undertaken in Israel and developing countries like Nigeria (2000–2004, 1991–1993, 1987–1989, 1981–1984), India (2000–2004, 1998), Botswana (1998–1999), Uganda (1995–1996), Ethiopia (1989–1990), Kenya (1988, 1986), Cameroon (1987), Gambia (1985) and Nicaragua (1978).

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