RECYCLE AND REUSE OF DOMESTIC WASTEWATER

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Keywords: Blackwater, Dual reticulation, Graywater, Pathogens, Reclamation, Recycle, Reuse, Sludge

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Summary

Reuse of wastewater for domestic and agricultural purposes has been occurring since historical times. However, planned reuse is gained importance only two or three decades ago, as the demands for water dramatically increased due to technological advancement, population growth, and urbanization, which put great stress on the natural water cycle. Reuse of wastewater for water-demanding activities, which, so far consumed limited freshwater resources is, in effect, imitating the natural water cycle through engineered processes. Several pioneering studies have provided the technological confidence for the safe reuse of reclaimed water for beneficial uses. While initial emphasis was mainly on reuse for agricultural and non-potable reuses, the recent trends prove that there are

direct reuse opportunities to applications closer to the point of generation. There are also many projects that have proved to be successful for indirect or direct potable reuse. All the case studies presented in this article point towards the potential wastewater has to serve as a viable alternative source of water, in future.

1. Introduction

The total supply of freshwater on earth far exceeds human demand. Hydrologists estimated that if all the water available on the planet—from oceans, lakes and rivers, the atmosphere, underground aquifers, and in glaciers and snow—could be spread over the surface, the earth would be flooded to an overall depth of some three kilometers. About 97 percent of this water is in the oceans, and out of the remaining three percent, only about one-hundredth is the accessible freshwater that can be used for human demand. If this available water could be evenly distributed, still it is enough to support a population about ten times larger than today. The foremost use of water by humans is for the biological survival. However, water need for the biological survival is not the only issue being discussed in the world today. Because, apart from drinking, water is required also for household needs such as cooking, washing, and is vital for our development needs, such as for agriculture and industry.

Unfortunately, the available freshwater supplies are not evenly distributed in time and space. Historically, water management has focused on building dams, reservoirs, and diversion canals etc., to make available water wherever needed, and in whatever amount desired. Soaring demands due to rapidly expanding population, industrial expansion, and the need to expand irrigated agriculture, were met by ever larger dams and diversion projects. Dams, river diversions, and irrigation schemes affected both water quality and quantity.

Demands on water resources for household, commercial, industrial, and agricultural purposes are increasing greatly. The world population will have grown 1.5 times over the second half of the twenty-first century, but the worldwide water usage has been growing at more than three times the population growth. In most countries human populations are growing while water availability is not. What is available for use, on a per capita basis, therefore, is falling. Out of 100 countries surveyed by the World Resources Institute in 1986, more than half of them were assessed to have low to very low water availability, and quality of water has been the key issue for the low water availability. Given the rapid spread of water pollution and the growing concern about water availability, the links between quantity and quality of water supplies have become more apparent. In many parts of the world, there is already a widespread scarcity, gradual destruction and increased pollution of freshwater resources.

In industrialized countries, widespread shortage of water is caused due to contamination of ground and surface water by industrial effluents, and agricultural chemicals. In many developing countries, industrial pollution is less common, though they are severe near large urban centers. However, untreated sewage poses acute water pollution problems that causes low water availability. Development of human societies is heavily dependent upon availability of water with suitable quality and in adequate quantities, for a variety of uses ranging from domestic to industrial supplies. An estimate infers that every year, the wastewater discharges from domestic, industrial and agricultural practices pollute more than two-thirds of total available run-off through rainfall, thereby, what can be called a "man-made water shortages." Thus, in spite of seeming abundance, water scarcity is endemic in most parts of the world. It is because of these concerns, the Agenda 21 adopted by the United Nations Conference on Environment and Development, popularly known as the "Earth Summit" of Rio de Janeiro, 1992, identified protection and management of freshwater resources from contamination as one of the priority issue, that has to be urgently dealt with to achieve global environmentally sustainable development.

The need for increased water requirement for the growing population in the new century is generally assumed, without considering whether available water resources could meet these needs in a sustainable manner. The question about from where the extra water is to come, has led to a scrutiny of present water use strategies. A second look at strategies has thrown a picture of making rational use of already available water, which if used sensibly, there could be enough water for all. The new look invariably points out at recycle and reuse of wastewater that is being increasingly generated due to rapid growth of population and related developmental activities, including agriculture and industrial productions.

2. History of Wastewater Reuse

The term "wastewater" properly means any water that is no longer wanted, as no further benefits can be derived out of it. About 99 percent of wastewater *is* water, and only one percent is solid wastes. An understanding of its potential for reuse to overcome shortage of freshwater existed in Minoan civilization in ancient Greece, where indications for utilization of wastewater for agricultural irrigation dates back to 5000 years. Sewage farm practices have been recorded in Germany and UK since 16th and 18th centuries, respectively. Irrigation with sewage and other wastewaters has a long history also in China and India.

In the more recent history, the introduction of waterborne sewage collection systems during the 19th century, for discharge of wastewater into surface water bodies led to indirect use of sewage and other wastewaters as unintentional potable water supplies. Such unplanned water reuse coupled with inadequate water and wastewater treatment, resulted in catastrophic epidemics of waterborne diseases during 1840s and 50s. However, when the water supply links with these diseases became clear, engineering solutions were implemented that include the development of alternative water sources using reservoirs and aqueduct systems, relocation of water intakes, and water and wastewater treatment systems. Controlled wastewater irrigation has been practiced in sewage farms many countries in Europe, America and Australia since the turn of the current century.

For the last three decades or so, the benefits of promoting wastewater reuse as a means of supplementing water resources and avoidance of environmental degradation have been recognized by national governments. The value of wastewater is becoming increasingly understood in arid and semi-arid countries and many countries are now looking forward to ways of improving and expanding wastewater reuse practices.

Research scientists, aware of both benefits and hazards, are evaluating it as one of the options for future water demands.

3. Motivational Factors for Recycling/Reuse

Major among the motivational factors for wastewater recycle/reuse are:

- opportunities to augment limited primary water sources;
- prevention of excessive diversion of water from alternative uses, including the natural environment;
- possibilities to manage in-situ water sources;
- minimization of infrastructure costs, including total treatment and discharge costs;
- reduction and elimination of discharges of wastewater (treated or untreated) into receiving environment;
- scope to overcome political, community and institutional constraints.

Reuse of wastewater can be a supplementary source to existing water sources, especially in arid/semi-arid climatic regions. Most large-scale reuse schemes are in Israel, South Africa, and arid areas of USA, where alternative sources of water are limited. Even in regions where rainfall is adequate, because of its spatial and temporal variability, water shortages are created. For example, Florida, USA is not a dry area, has limited options for water storage, and suffers from water shortages during dry spells. For this reason wastewater reuse schemes form an important supplement to the water resource of this region.

Costs associated with water supply or wastewater disposal may also make reuse of wastewater an attractive option. Positive influences on treatment costs of wastewater and water supplies, and scopes for reduction in costs of headworks and distribution systems, for both water supply and wastewater systems has been the motivation behind many reuse schemes in countries like Japan.

Reuse is frequently practiced as a method of water resources management. For example, depleted aquifers may be “topped-up” by injection of highly treated water, thus restoring aquifer yields or preventing saltwater intrusion (in coastal zones).

Avoidance of environmental problems arising due to discharge of treated/untreated wastewater to the environment is another factor that encourages reuse. While the nutrients in wastewater can assist plant growth when reused for irrigation, their disposal, in extreme cases, is detrimental to ecosystems of the receiving environment. In addition, there may be concerns about the levels of other toxic pollutants in wastewater.

Concern about water supply or environmental pollution may emerge as a political or institutional issue. Community concern about the quality of wastewater disposed to sensitive environments may lead to political pressures on the water industry to treat wastewater to a higher level before discharge, that can be avoided through reuse of wastewater. Institutional structures may also provide incentives for reuse. Because responsibility for different parts of water use and disposal system may rest with different organizations, a water utility may also be faced with standards of service set in agreements with other industry bodies.

4. Quality Issues of Wastewater Reuse/Recycling

Despite a long history of wastewater reuse in many parts of the world, the question of safety of wastewater reuse still remains an enigma mainly because of the quality of reuse water. There always have been controversies among the researchers and proponents of extensive wastewater reuse, on the quality the wastewater is to meet. In general, public health concern is the major issue in any type of reuse of wastewater, be it for irrigation or non-irrigation utilization, especially *long term impact of reuse practices*. It is difficult to delineate acceptable health risks and is a matter that is still hotly debated.
Issues other than quality of reuse water includes, socioeconomic considerations, and hydro-geologic conditions. The socioeconomic considerations include community perceptions, and the costs of reuse systems. Wide community level surveys in various States of Australia during early 1990s indicated that in general, public is not averse to the concept of wastewater recycling within the community. In one of such surveys, however, less than 15% readily agreed for potable reuse. While non-potable reuse options was a technically accepted option, concerns about possible health risks were frequently raised by the public. Documented public health investigations available in USA is given in US Environmental Protection Agency Guidelines which considered that epidemiological studies of exposed populations at water reuse sites are of limited value, because of the mobility of the population, small sizes of such study populations, and difficulties in determining the actual level of exposure of each studied individual. Despite the limitations of epidemiological investigations, the wastewater reuse in the US has not been implicated as the cause of any infectious disease outbreaks. A more specific study of the city of St. Petersburg, Florida to estimate the potential risk to the exposed population concluded that:

- there is no evidence of increased enteric diseases in urban regions housing areas irrigated with treated reclaimed wastewater, and
- there is no evidence of significant risks of viral or microbial diseases as a result of exposure to effluent aerosols from spray irrigation with reclaimed water.

However, the study recommended that adequate treatment schemes must always be designed to eliminate, or at least minimize the potential risks of disease transmission.

The economic considerations are necessary because, when “first-hand” water is available at a cheaper price, it may not be worthwhile to reuse wastewater, unless there are other special conditions. Consideration of hydro-geologic conditions helps to compare the reuse water quality and the quality of alternative sources intended for the same kind of use.

Almost all the guidelines and standards for wastewater reuse deal mainly with the reuse of wastewater for irrigation purpose. It is mainly because irrigation is the highest water consuming activity in any country, and hence is the first option considered in any reuse planning. For example, 90 percent of available water supply in the Indian subcontinent, and a staggering 98 percent in Egypt, is used in irrigation. Though there are no generalized guidelines for reuse water quality for other options, in countries like Japan, where domestic reuse also is widely practiced, there are standards for such reuse.

4.1 Pathogen Survival

Public health concerns center around pathogenic organisms that are or could be present in wastewater in great variety. Survival of pathogens in wastewater and in environmental conditions other than their host organisms (mainly humans) is highly variable. Table 1 presents the survival periods of various types of pathogenic organisms under various conditions.

Type of pathogen	**Survival time in days**			
	In feces and sludge	**In sewage and freshwater**	**In soil**	**On crops**
1. Viruses				
Enteroviruses	<100 (<20)	<120 (<50)	<100 (<30)	<60 (<15)
2. Bacteria				
Fecal coliforms	<90 (<50)	<60 (<30)	<70 (<20)	<30 (<15)
Salmonella spp.	<60 (<30)	<60 (<30)	<70 (<20)	<30 (<15)
Shigella spp.	<30 (<10)	<30 (<10)	-	<10 (<5)
Vibrio cholerae	<30 (<5)	<30 (<10)	<20 (<10)	<5 (<2)
3. Protozoa				
Entamoeba-hystolytica cysts	<30 (<15)	<30 (<15)	<20 (<10)	<10 (<2)
4. Helminths				
Ascaris-lumbricoides eggs	many months	many months	many months	<60 (<30)

Figures in bracket shows the normal survival time.
Source: Feachem R. G., Bradley D. J., Garelick H. and Mara D. D. (1983). World sanitation and disease: health aspects of excreta and wastewater management by Bank Studies. In *Water Supply Sanitation Vol. 3* Chichester, UK: John Wiley & Sons

Table 1. Survival of pathogens

While emphasizing the need to assess health hazards of wastewater reuse and the importance of various routes of transmission, from direct contact, through food or air, to indirect contact such as in recreational use, there also is a need to recognize the existence of many successive barriers. The barriers include the level of wastewater treatment previously applied leading to settling, adsorption, desiccation of pathogens, as well as soil moisture, temperature, UV irradiation due to sunlight, pH, antibiotics, toxic substances, biological competition, available nutrient and organic matter, leading to pathogen die-away and/or removal from the wastewater source until final ingestion by humans to result in infection. The method and time of application of wastewater and the soil type will also have an influence. Extensive and rational epidemiological studies have led to a consensus view that the actual risk associated with irrigation with treated wastewater is much lower than previously estimated, and the early microbiological standards were unjustifiably restrictive for wastewater reuse.

Another aspect of indirect pathogen contamination due to wastewater reuse has been the contamination of soil and subsequent entry of pathogen into groundwater. The principal methods of pathogen transport in soils include movement downwards with infiltration water, movement with surface runoff and transport on sediments and waste particles. Long-term research studies carried out to understand this effect have concluded that no soil or groundwater quality degradation occurred due to prolonged wastewater application. One of the important processes that controls the contamination of groundwater is the adsorption or retention of organisms on soil particles. Another process assisting in the removal of bacteria and viruses from water percolating through the soil is filtration.

4.2 Other Water Quality Parameters

Other water quality parameters of concern in wastewater reuse have been toxic metal accumulation and salinity of wastewater. The availability of heavy metals to plants, their uptake and their accumulation depend on a number of soil, plant and other factors. The soil factors include, soil pH, organic matter content, cation exchange capacity, moisture, temperature and evaporation. Major plant factors are the species and variety, plant parts used for consumption, plant age and seasonal effects.

Dissolved salts causing salinity in wastewater exert an osmotic effect on plant growth. An increase in osmotic pressure of the soil solution increases the amount of energy which the plant must expend to take up water from the soil. As a result, respiration is increased and the growth and yield of plants decline. However, it has been found that not all plant species are susceptible. A wide variety of crops normally are tolerant to salinity. Salinity also affects the soil properties such as dispersion of particles, stability of aggregates, soil structure and permeability.

4.3 Effluent Quality Standards

Considering the wide-ranging potential for wastewater reuse, it may be difficult to set some common quality standards for all types of reuses. Many countries in the world do not have detailed standards or guidelines for recycle and reuse of wastewater. For many countries in Europe, either the guidelines of World Health Organization (WHO) or the US Environmental Protection Agency (USEPA) standards form the basis for any decision or for granting permission to any kind of reuse. Countries like old USSR, Israel and Tunisia have developed their own standards for reuse. Standards or guidelines for other possible reuses such as groundwater recharge, industrial uses etc., are not common, mainly because such types of reuses are not widespread.

First water quality criteria for reuse of wastewater in irrigation were set in 1933, by the California State Health Department. These standards are for microbiological parameters that indicate the presence of pathogenic organisms in wastewater. In 1971, the WHO meeting of experts on reuse of wastewater recognized that mere presence of pathogens is not sufficient to declare water for reuse as unsafe, and considered that the California standards were overly strict and hindered widespread reuse practice, and recommended a much relaxed microbiological standard for wastewater irrigation. Table 2 presents the microbiological quality guidelines for wastewater reuse in agriculture, recommended by WHO.

Standards for other polluting parameters are intended to prevent pollutant inputs becoming harmful to consumers of the harvested food, and to the soil. If pollutants are allowed to accumulate in the soil, its potential use, over the long term, may become limited. By regulating land application, accumulation of pollutants in the wastewater receiving soil can be prevented. However, it is often argued that reuse regulations based on stringent pollutant loading limits, tend to discourage the land application option. Moreover, such limits do not consider the capacity of soils to attenuate pollutants. Through proper management of land applications, the agronomic benefits of wastewater can be realized, and accumulation of pollutants in the soil can be controlled not to reach harmful levels. A comparison of water quality standards for physico-chemical, and toxic polluting parameters for irrigation reuse of wastewater in some of the countries of the world is presented in Appendix I.

Reuse condition	**Exposed group**	**Intestinal nematodes***	**Fecal coliforms+**	**Wastewater treatment expected to achieve the quality**
Category A: Irrigation of crops likely to be eaten uncooked, sports fields, public parks	Workers, consumers, public	≤ 1	≤ 1000	A series of stabilization ponds designed to achieve the microbiological quality indicated or equivalent treatment.
Category B: Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees++	Workers	≤ 1	Not applicable	Retention in stabilization ponds for 8-10 days or equivalent helminth and fecal coliform removal
Category C: Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but no less than primary sedimentation.

* Arithmetic mean no. of eggs per 100 ml
\+ Geometric mean no. per 100 ml
++ In case of fruit trees, irrigation should cease 2 weeks before fruit is picked
Source: *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture.* Technical report series No. 778, World Health Organization, Geneva, 1989.

Table 2. WHO microbiological quality guidelines for wastewater reuse in agriculture

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Biographical Sketches

Dr. S. Vigneswaran is currently a Professor and a Head of Environmental Engineering Group in Faculty of Engineering, University of Technology, Sydney, Australia. He has been working on water and wastewater research since 1976. He has published over 175 technical papers and authored two books (both through CRC press, USA). He has established research links with the leading laboratories in France, Korea, Thailand, and the USA. Also, he has been involved in number of consulting activities in this field in Australia, Indonesia, France, Korea and Thailand through various national and international agencies. Presently, he is coordinating the university key research strengths on "water and waste management in small communities," one of the six key research centers funded by the university on competitive basis. His research in solid liquid separation processes in water and wastewater treatment namely filtration, adsorption is recognized internationally and widely referred.

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