20 Municipal Wastewater Management in India

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Introduction

Water is vital to the existence of all living organisms, but this valued resource is increasingly being threatened as human populations grow and demand more water of high quality for domestic purposes and economic activities. Among the various environmental challenges of that India is facing this century, fresh water scarcity ranks very high. The key challenges to better management of the water quality in India are temporal and spatial variation of rainfall, improper management of surface runoff, uneven geographic distribution of surface water resources, persistent droughts, overuse of groundwater, and contamination, drainage, and salinization and water quality problems due to treated, partially treated, and untreated wastewater from urban settlements, industrial establishments, and run-off from the irrigation sector besides poor management of municipal solid waste and animal dung in rural areas.

India, being an economy in transition from a developing to a developed nation, faces two problems. On the one hand there is a lack of infrastructure and on the other, an ever-increasing urban population. The urban population in India has jumped from 25.8 million in 1901 to about 387 million (estimated) in 2011. This has thrown up two self-perpetuating problems, viz. shortage of water and sewage overload. It is estimated that by 2050, more than 50 per cent of the country's population will live in cities and towns and thus the demand for infrastructure facilities is expected to rise sharply, posing a challenge to urban planners and policymakers.

Public services have not been able to keep pace with rapid urbanization. Water supply, sanitation measures, and management of sewage and solid wastes cover only a fraction of the total urban population. There is clear inequity and disparity between the public services received by the inhabitants, depending on their economic strata. Slum dwellers have always received least attention from the civic authorities. The rapid growth of urban population has taken place due to huge migration of population (mostly from rural areas and small towns to big towns) and inclusion of newer rural areas in the nearest urban settings, apart from natural growth of urban population. The majority of towns and cities have no sewerage and sewage treatment services. Many cities have expanded beyond municipalities, but the new urban agglomerations remain under rural administrations, which do not have the capacity to handle the sewage. Management of sewage is worse in smaller towns. The sewage is either directly dumped into rivers or lakes or in open fields.

Wastewater Generation and Treatment

It is estimated that about 38,254 million litres per day (mld) of wastewater is generated in urban centres comprising Class I cities and Class II towns having population of more than 50,000 (accounting for more than 70 per cent of the total urban population). The municipal wastewater treatment capacity developed so far is about 11,787 mld, that is about 31 per cent of wastewater generation in these two classes of urban centres. The status of wastewater generation and treatment capacity developed over the decades in urban centres (Class I and Class II) is presented in Table 20.1. In view of the population increase, demand of freshwater for all uses will become unmanageable. It is estimated that the projected wastewater from urban centres may cross 120,000 mld by 2051 and that rural India will also generate not less than 50,000 mld in view of water supply designs for community supplies in rural areas (see Table 20.2). However, wastewater management plans do not address this increasing pace of wastewater generation.

Central Pollution Control Board (CPCB) studies depict that there are 269 sewage treatment plants (STPs) in India, of which only 231 are operational, thus, the existing treatment capacity is just 21 per cent of the present sewage generation. The remaining untreated sewage is the main cause of pollution of rivers and lakes. The large numbers of STPs created under Central Funding schemes such as the Ganga Action Plan and Yamuna Action Plan of National River Action Plan are not fully operated. The operation and maintenance (O&M) and power cost in some of the typical sewage treatment plants is presented in Table 20.3.

The development process in India is gaining momentum and the rural population which is devoid of basic infrastructural facilities will have to be given parity in terms of water supply and sanitation. This process of change is likely to generate huge volume of wastewater in rural areas as well. It would be appropriate to design water and wastewater management plans optimally so that competing pressures on water resources can be eased.

There is a need to plan strategies and give thrust to policies giving equal weightage to augmentation of supplied water as well as development of wastewater treatment facilities, recycling, recovery, recharging, and storage. The future of urban water supply for potable uses will depend majorly on efficient wastewater treatment systems, as the treated wastewater of upstream urban centres will be the source of water for downstream cities. This chapter tries to deal with the various issues of sanitation and health.

Present Practices of Wastewater Reuse

The volume of wastewater generated by domestic, industrial, and commercial sources has increased with population, urbanization, improved living conditions, and economic development. The productive use of wastewater has also increased, as millions of small-scale farmers in urban and peri-urban areas of developing countries depend on wastewater or wastewater polluted water sources to irrigate high-value edible crops for urban markets, often because they have no alternative sources of irrigation water. Conventionally, sewage is

Table 20.1 Wastewater Generation and Treatment Capacity in Urban Centres

Parameters	*Class I cities*					*Class II towns*				
	1978–9	*1989–90*	*1994–5*	*2003–4*	*2009*	*1978–9*	*1989–90*	*1994–5*	*2003–4*	*2009*
Number	142	212	299	423	423	190	241	345	498	498
Population (millions)	60	102	128	187	187	12.8	20.7	23.6	37.5	37.5
Water Supply (mld)	8638	15,191	20,607	29,782	44,448	1533	1622	1936	3035	3371
Wastewater Generated (mld)	7007	12,145	16,662	23,826	35,558	1226	1280	1650	2428	2696
Wastewater treated (mld) (per cent)	2756 (39)	2485 (20.5)	4037 (24)	6955 (29)	11,553	67 (5.44)	27 (2.12)	62 (3.73)	89 (3.67)	234
Wastewater untreated (mld) (per cent)	4251 (61)	9660 (79.5)	12,625 (76)	16,871 (71)	24,004	1160 (94.56)	1252 (97.88)	1588 (96.27)	2339 (96.33)	2463

Source: Bhardwaj (2005).

Table 20.2 Wastewater Generation from Urban Centres, Projections for 2051

Year	*Urban population (million)*	*Wastewater generation lpcd*	*Gross wastewater generation (mld)*
1977–8	72.8	116	7007
1989–90	122.7	119	12145
1994–5	151.6	130	16662
2003–4	243.5	121	26254
2009	316.15	121	38254
2051	1000 (Projected)	121 (Assumed)	120000 (Projected)

Source: Bhardwaj (2005).
Note: lpcd–litres per capita per day.

collected through a vast network of sewerage systems and transported to a centralized treatment plant, which is resource intensive. Instead of transporting it long distance for centralized treatment, the Central Pollution Control Board is promoting decentralized treatment at the local level using technology based on natural processes. After proper treatment, sewage can be used in pisciculture, irrigation, forestry, and horticulture. Its conventional treatment generates sludge, which acts as manure. The sludge can also be used for energy recovery. Some STPs in the country are recovering this energy and utilizing it.

Municipal wastewater can be recycled for irrigation purposes or for usage in industry/thermal power stations as utility water (cooling towers/boilers). The wastewater may be given some form of terminal treatment before its application on land. The remaining nutrients, organics, and water enter the natural system of recycling and are used by plants and microbes in soil or are retained by the soil. In the process, excess water percolates through the soil medium, gets renovated, and ultimately recharges the groundwater. The principal of reuse/recycling of wastewater differs from the age-old sewage farming practices as the present technology, that is, 'Land Treatment' means a controlled application of pre-treated wastewater on land surface to achieve a designated degree of treatment through natural bio-geochemical process wastewater reuse. This involves: (i) slow rate (SR)—(a) treatment of applied wastewater based on assimilative capacity of soil, (b) economic return from reuse of water and nutrients to produce marketable crops, (c) water conservation; (ii) rapid infiltration (RF)—(a) groundwater recharge, (b) recovery of renovated water; and (iii) overland flow (OF)—(a) wastewater treatment with the help of low permeable and sloping land, (b) recycling of renovated water from the system, (c) crop production.

New generation of sewage treatment technologies such as membrane bioreactor (MBR) can treat the wastewater near to the quality of river water. With suitable renovation this treated sewage can also recharge flood plains of riverine systems to ensure perennial flow of rivers. It is pertinent to mention that the cost for activated sludge process is around Rs 90 lakh to 1 crore for 1 MLD sewage while that for MBR is Rs 1.3–1.5 crore for 1 MLD sewage. If the treated sewage from MBR technique is recycled to industry as a substitute of fresh water for non process uses the revenue generation shall be significant.

In fact there shall be a paradigm shift with respect to sewage management; that is, from sewage treatment to sewage reuse and recycling.

There are several opportunities for improving wastewater irrigation practices via improved policies, institutional dialogue, and financial mechanisms, which would reduce risks in agriculture. Effluent standards combined with incentives or enforcement can motivate improvements in water management by household and industrial sectors discharging wastewater from point sources. Segregation of chemical pollutants from urban wastewater facilitates treatment and reduces risk. Strengthening institutional capacity and establishing links between water delivery and sanitation sectors through inter-institutional coordination leads to more efficient management of wastewater and risk reduction.

Health Aspects

Undesirable constituents in wastewater can harm human health as well asthe environment. Hence, wastewater irrigation is an issue of concern to public agencies responsible for maintaining public health and environmental quality (see Box 20.1). For diverse reasons, many developing countries are still unable to implement comprehensive wastewater treatment programmes. Therefore in the near term, risk management

Table 20.3 STP—O&M and Power Costs (per m^3 of sewage treated)

Plant	*MLD*	*Technology*	*O&M cost annual in Rs lakh*	*Rs /m³*	*Power cost (Lakh) units/day*	*per day*	*Rs/m³*	*Total cost Rs/m³*	*Remarks*
Sen Nursing Home and Delhi Gate Nala Plants—Delhi	2 × 10	Densadeg + Biofor	126	1.73	5,680	0.26	1.28	3.01	With chemical dosing
STP at Raja canal—Bengaluru	40	Extended aeration	83	0.57	7,863	0.3	0.74	1.31	With Nitrification and Denitrification
TTP at V Valley—Bengaluru	60	Biotower + Densadeg + Biofor-F	269	1.14	8,650	0.32	0.54	1.68	With Chlorination
STP at Rithala—Delhi	182	HLASP + Biofor-F	550	0.87	15,000	0.9	0.38	1.25	No Chlorination
TTP at Lalbagh- Bengaluru	1.5	Classical Tertiary Treatment+UV+Cl	28	5.11	1450	0.05	3.63	8.74	From raw sewage to TTP + Chlorination
TTP at Cubbon park—Bengaluru	1.5	MBR + UV+Cl	30	5.48	1650	0.06	4.13	9.61	From raw sewage BOD/TSS<3, Coliform<23mpn

Source: Grover (2011).

Box 20.1
Sewage Irrigated Vegetable Production: Water Reuse or Abuse

In many Tier II and smaller cities and towns in India, untreated sewage water is being used for the irrigation of vegetables. Most farming geared to supplying urban areas takes place on peri-urban fringes where sewage is easily accessible. While planned use of sewage water is estimated to be large in many countries,—for example, 67 per cent of the total effluent in Israel, 25 per cent in India, and 24 per cent in South Africa—unplanned use is reportedly much higher (Blumenthal et al. 2000). It is primarily unplanned use, where the water is not treated adequately prior to use, that poses significant health and ecological problems.

There are numerous benefits to using treated sewage water (STW) in agriculture.

1. In the face of growing water scarcity, using STW for agriculture alleviates the competing demands on freshwater from industry and households. In particular, it frees up potable water for the growing drinking water demands.
2. By diverting sewage that would otherwise be pumped into freshwater bodies or the sea, STW helps reduce pollution and its attendant health risks.
3. Some studies indicate that using STW with its high nutrient content can increase crop yields between 10–30 per cent (Asano 1998, cited in Afifi et al. 2011).
4. STW provides an easily accessible, cost-effective option for small urban and peri-urban farmers and is of particular value during the dry season when other sources of water dry up. Bradford et al. (2003) estimate that using *untreated* sewage water is considerable cheaper than constructing a borehole for pumping groundwater.

At the same time, there are numerous risks involved with using STW. However, it appears that the most serious risks relate to using untreated sewage rather than STW. Numerous studies have shown evidence of intestinal nematode infections and bacterial infections as a result of eating crops grown with untreated sewage water. Diseases such as cholera and typhoid are also transmitted through this route as are non-essential heavy metals that in the long term can lead to kidney disease (Ghafoor et al. 1995; Nriagu 1990; Ferrecio et al.1984; and Shuval et al. 1986 cited in Blumenthal et al. 2000). Farmers coming in constant contact with untreated sewage water are also at risk of contracting a host of water-borne and water-vector diseases even if they do not ingest the crops they grow. Last, irrigation with untreated wastewater often leads to soil structure degradation (soil clogging or 'sewage sickness) and problems such as salinization, phytotoxicity (plant poisoning) (Bradford et al. 2003). The high nutrient content also encourages the growth of weeds and pests which consequently increases both labour costs and pesticide usage (Ibid.)

Fortunately, most of these risks can be abated by treating sewage water properly. A manual for use of treated sewage for vegetable production has been prepared by the Food and Agriculture Organization (FAO) of the United Nations as reported in a paper entitled 'Wastewater Treatment and Use in Agriculture', available at http://www.fao.org/docrep/T0551E/t0551e00.htm#Contents. The technologies suitable for meeting the stipulated guidelines include waste stabilization ponds (WSP) or wastewater storage and treatment reservoirs (WSTR). These technologies are land intensive, but have negligible energy requirements and O&M are minimal. While more expensive technology can also be used for better quality output, the costs of using the WSP and similar more basic technologies can be easily recovered in the sale of produce. However, care should be taken to ensure consistent output quality.

Suitable policy measures need to be formulated to encourage the reuse of treated sewage for irrigation purposes. Measures may include incentives to Urban Local Bodies (ULBs) to construct treatment devices using relevant technology, instituting a State Level Water Sector Regulator to regulate tariff and quality standards of fresh and reuse water, and water users' committees responsible for the operation and management of the STPs in the respective ULBs. Last, municipalities could treat sewage as per their CPCB obligations and supply it to famers to leverage this nutrient rich waste and potentially even turn it into a revenue stream for themselves.

Source: Afifi et al. (2011); Blumenthal et al. (2000); and Bradford et al. (2003).

—Palash Srivastava

and interim solutions are needed to prevent adverse impacts from wastewater irrigation. A combination of source control, and farm-level and post-harvest measures can be used to protect farm workers and consumers. The World Health Organization (WHO) guidelines (revised in 2006) for wastewater use suggest measures beyond the traditional recommendations of producing only industrial or non-edible crops; as in many situations it is impossible to enforce a change in the current cash crop pattern or provide alternative vegetable supply to urban markets.

Developed economies regard wastewater treatment as vital for protecting human health and preventing the contamination of lakes and rivers. However, for most developing countries this solution is prohibitively expensive. In this case, applying wastewater to agricultural lands is a more economical alternative and more ecologically sound than uncontrolled dumping of municipal and industrial effluents into lakes and streams. Obviously, the short-term benefits of wastewater irrigation could be offset by the health and environmental impacts. The first step is to scientifically evaluate these. Once the actual risks are clear, we can work towards reducing them. This means, for example, finding affordable ways of monitoring the presence of harmful contaminants in wastewater, such as heavy metals that can accrue in soil and crops. It also means looking at farming practices and crops grown to find ways of minimizing risks of infection for farmers.

Raw domestic wastewaters normally carry the full spectrum of pathogenic microorganisms—the causative agents of bacterial, virus, and protozoan diseases endemic in the community and excreted by diseased and infected individuals. While recycling and reuse of wastewater for agriculture, industry, and non-potable urban purposes can be a highly effective strategy for developing a sustainable water resource in water-scarce areas, nutrient conservation, and environmental protection, it is essential to understand the health risks involved and to develop appropriate strategies for the control of those risks. There is need to concentrate on the control of pathogenic microorganisms from wastewater in agricultural reuse since this is the most widely practiced form of reuse in India. However, more and more water specialists, natural resource planners, and economists see water as an economic good and, as time goes on, there will be an increased motivation to divert recycled wastewater from low income agriculture to areas where the added value of water is greater, such as industrial and non-potable urban uses including public parks, green belts, and golf courses. As time goes on and water shortages in arid areas increase, there will undoubtedly be an expansion of the reuse of purified wastewater for industrial and a wide variety of urban non-potable purposes. Concern for human health and the environment are the most important constraints in the reuse of wastewater. While the risks need to be carefully considered, the importance of this practice for the livelihoods of countless small holders must also be taken into account. There is need for research on wastewater irrigation to maximize the benefits to the poor who depend on the resource while minimizing the risks. Many wastewater irrigators are not landowning farmers, but landless people that rent small plots to produce income-generating crops such as vegetables that thrive when watered with nutrient-rich sewage. Across the country, these wastewater micro-economies support countless poor people. Stopping or over-regulating these practices could remove the only source of income of many landless people.

Wastewater Treatment Technologies

Wastewater Treatment Plant is a facility designed to receive the waste from domestic, commercial, and industrial sources and to remove materials that damage water quality and compromise public health and safety when discharged into water receiving systems. The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed off without danger to human health or unacceptable damage to the natural environment.

Conventional Wastewater Treatment Processes

Conventional wastewater treatment consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter, and sometimes, nutrients from wastewater.

Preliminary Treatment

The objective of preliminary treatment is the removal of coarse solids and other large materials often found in raw wastewater. Removal of these materials is necessary to enhance the O&M of subsequent treatment units. Preliminary treatment operations typically include coarse screening, grit removal, and, in some cases, communication of large objects.

Primary Treatment

The objective of primary treatment is the removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that will float (scum) by skimming.

Secondary Treatment

The objective of secondary treatment is the further treatment of the effluent from primary treatment to remove the residual organics and suspended solids. In most cases, secondary treatment follows primary treatment and involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. Aerobic biological treatment is performed in the presence of oxygen by aerobic microorganisms (principally bacteria) that metabolize the organic matter in the wastewater, thereby producing more microorganisms and inorganic end-products (principally CO_2, NH_3, and H_2O). Several aerobic biological processes are used for secondary treatment differing primarily in the manner in which oxygen is supplied to the microorganisms and in the rate at which organisms metabolize the organic matter. Common high-rate processes include the activated sludge processes, trickling filters or bio-filters, oxidation ditches, and rotating biological contractors (RBCs). A combination of two of these processes in series (for example bio-filter followed by activated sludge) is sometimes used to treat municipal wastewater containing a high concentration of organic material from industrial sources.

Various commonly used treatment technologies in India for treatment of sewage and industrial effluents are summarized here.

Activated Sludge Process

The most common suspended growth process used for municipal wastewater treatment is the activated sludge process. The municipal wastewater treatment is the Biochemical Oxygen Demand (BOD) removal. The removal of BOD is done by a biological process, such as the suspended growth treatment process. This biological process is an aerobic process and takes place in the aeration tank, in which the wastewater is aerated with oxygen. By creating good conditions, bacteria will grow fast. The growth of bacteria creates flocks and gases. These flocks are removed by a secondary clarifier. In the activated sludge process, the dispersed-growth reactor is an aeration tank or basin containing a suspension of the wastewater and microorganisms, the mixed liquor. The contents of the aeration tank are mixed vigorously by aeration devices which also supply oxygen to the biological suspension. Commonly used aeration devices include submerged diffusers that release compressed air and mechanical surface aerators that introduce air by agitating the liquid surface. Hydraulic retention time in the aeration tanks usually ranges from 3 to 8 hours but can be higher with high BOD wastewaters. Following the aeration step, the microorganisms are separated from the liquid by sedimentation and the clarified liquid is secondary effluents. A portion of the biological sludge is recycled to the aeration basin to maintain a high mixed-liquor suspended solid (MLSS) level. The remainder is removed from the process and sent to sludge processing to maintain a relatively constant concentration of microorganisms in the system. Several variations of the basic activated sludge process, such as extended aeration and oxidation ditches, are in common use, but the principal is similar.

Trickling Filters

A trickling filter or bio-filter consists of a basin or tower filled with support media such as stones, plastic shapes, or wooden slats. Wastewater is applied intermittently, or sometimes continuously, over the media. Microorganisms become attached to the media and form a biological layer or fixed film. Organic matter in the wastewater diffuses into the film, where it is metabolized. Oxygen is normally supplied to the film by the natural flow of air either up or down through the media, depending on the relative temperatures of the wastewater and ambient air. Forced air can also be supplied by blowers but this is rarely necessary. The thickness of the bio-film increases as new organisms grow. Periodically, portions of the film slough off the media. The sloughed material is separated from the liquid in a secondary clarifier and discharged to sludge processing. Clarified liquid from the secondary clarifier is the secondary effluent and a portion is often recycled to the bio-filter to improve hydraulic distribution of the wastewater over the filter.

Rotating Biological Contactors

Rotating biological contactors (RBCs) are fixed-film reactors similar to bio-filters in that organisms are attached to the support media. In the case of the RBCs, the support media are slowly rotating discs that are partially submerged in flowing wastewater in the reactor. Oxygen is supplied to the attached biofilm from the air when the film is out of the water and from the liquid when submerged, since oxygen is transferred to the wastewater by surface turbulence created by the rotation of the discs. Sloughed pieces of biofilm are removed in the same manner described for bio-filters.

High-rate biological treatment processes, in combination with primary sedimentation, typically remove 85 per cent of the BOD and Suspended Solid (SS) originally present in the raw wastewater and some of the heavy metals. Activated sludge generally produces an effluent of slightly higher quality, in terms of these constituents, than bio-filters or RBCs. When coupled with a disinfection step, these processes can provide substantial but not complete removal of bacteria and viruses. However, they remove very little phosphorus, nitrogen, non-biodegradable organics, or dissolved minerals.

Up-flow Anaerobic Sludge Blanket (UASB) Process

The UASB is an anaerobic process whilst forming a blanket of granular sludge and suspended in the reaction tank. Wastewater flows upwards through the blanket and is processed by the anaerobic microorganisms. The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants. The blanket begins to reach maturity at around three months. Small sludge granules begin to form whose surface area is covered in aggregations of bacteria. In the absence of any support matrix, the flow conditions create a selective environment in which only those microorganisms, capable of attaching to each other, survive and proliferate. Eventually the aggregates form into dense compact bio-films referred to as 'granules'. The fine granular sludge blanket acts as a filter to prevent the solids in the incoming wastes to flow through as the liquid part does. So if the hydraulic retention time (HRT) does not change, which is limited to 1–3 days (the bigger the digester, the shorter time it is, because the size costs money), the solid retention time (SRT) can be 10–30 days or more for more effective digestion, depending on the shape of the digestion chamber. This means that the digester becomes much more efficient without having to increase the size, which costs money. Standing and hanging baffles are used, with a conic separation and a small outlet at the centre; this is much more effective in keeping the anaerobic sludge blanket in the lower part of the digester. This also acts as a very good filter to retard the flow of solids in the wastes and prolong the solid retention time for more bacterial action. However, the digester would be more economic if the loading can be increased for a specific size of digester with the conic separation.

Bio-chemical activities in UASB Digesters comprise of bacterial actions which have three phases and they occur in the following sequence:

- Hydrolysis or solubilization: The first phase takes 10–15 days, and until the complex organics are solubilized, they cannot be absorbed into the cells of the bacteria where they are degraded by the endoenzymes;
- Acidogenesis or acetogenesis: The result from stage one is utilized by a second group of organisms to form organic acids;
- Methanogenesis: The methane-producing (methanogenic) anaerobic bacteria then use the product from the second stage to complete the decomposition process.

Waste Stabilization Ponds

Wastewater stabilization pond technology is one of the most important natural methods for wastewater treatment. Waste stabilization ponds are mainly shallow man-made basins comprising a single or several series of anaerobic, facultative, or maturation ponds. The primary treatment takes place in the anaerobic pond, which is mainly designed to remove suspended solids, and some of the soluble elements of organic matter (BOD). During the secondary stage in the facultative pond most of the remaining BOD is removed through the coordinated activity of algae and heterotrophic bacteria. The main function of the tertiary treatment in the maturation pond is the removal of pathogens and nutrients (especially nitrogen). Waste stabilization pond technology is the most cost-effective wastewater treatment technology for the removal of pathogenic microorganisms. The treatment is achieved through natural disinfection mechanisms. It is particularly well suited for tropical and subtropical countries because the intensity of the sunlight and temperature are key factors in the efficiency of the removal processes.

ANAEROBIC PONDS

These units are the smallest of the series. Commonly they are 2–5 m deep and receive high organic loads equivalent to100g BOD/ meter^3 per day. These high organic loads produce strict anaerobic conditions (no dissolved oxygen) throughout the pond. In general terms, anaerobic ponds function much like open septic tanks and work extremely well in warm climates. A properly designed anaerobic pond can achieve around 60 per cent BOD removal at 20ºc. One-day hydraulic retention time is sufficient for wastewater with a BOD of up to 300 mg/l and temperatures higher than 20º c. Designers have always been preoccupied by the possible odour that these tanks might cause. However, odour problems can be minimized in well-designed ponds, if the $SO42_{-}$ concentration in wastewater is less than 500 mg/l. The removal of organic matter in anaerobic ponds follows the same mechanisms that take place in any anaerobic reactor.

FACULTATIVE PONDS

These ponds are of two types: primary facultative ponds receive raw wastewater, and secondary facultative ponds receive the settled wastewater from the first stage (usually the effluent from anaerobic ponds). Facultative ponds are designed for BOD removal on the basis of a low organic surface load to permit the development of an active algal population. This way, algae generate the oxygen needed to remove soluble BOD. Healthy algae populations give the water a dark green colour but occasionally they can turn red or pink due to the presence of purple, sulphide-oxidizing photosynthetic activity. This ecological change occurs due to a slight overload. Thus, the change of colouring in facultative ponds is a qualitative indicator of an optimally performing removal process. The concentration of algae in an optimally performing facultative pond depends on organic load and temperature, but is usually in the range 500 to 2000 µg chlorophyll per litre. The photosynthetic activity of the algae results in a diurnal variation in the concentration of dissolved oxygen and pH values. Variables such as wind velocity have an important effect on the behaviour of facultative ponds, as they generate the mixing of the pond liquid. Blumenthal et al. (2000) indicate that a good degree of mixing ensures a uniform distribution of BOD, dissolved oxygen, bacteria, and algae, and hence better wastewater stabilization. More technical details on the efficiency of the process and removal mechanisms can be found in Mara (2009).

MATURATION PONDS

These ponds receive the effluent from a facultative pond and the size and number depend on the required bacteriological quality of the final effluent. Maturation ponds are shallow (1.0–1.5 m) and show less vertical stratification, and their entire volume is well oxygenated throughout the day. Their algal population is much more diverse than that of facultative ponds. Thus, the algal diversity increases from pond to pond along the series. The main removal mechanisms especially of pathogens and faecal coliforms are ruled by algal activity in synergy with photo-oxidation. On the other hand, maturation ponds achieve only a small removal of BOD, but their contribution to nitrogen and phosphorus removal is more significant.

Aerated Lagoons

The mechanical-biological purification of wastewater takes place in one or more aerated lagoons according to the size of the plant, which are followed by a non-aerated sedimentation and polishing pond. The sewage coming from the canalization is normally led directly into the first aerated lagoon without mechanical pre-purification. So the continuous disposal of screenings, sand, and sedimentation sludge and its maintenance efforts can be omitted. Coarse stuff, sand, and heavy sludge settle in the inlet zone while dissolved contaminants are distributed in the whole first lagoon. Liable to putrefy matter should mainly be stabilized by aerobic processes to avoid odours and digested sludge coming up to the water surface. According to our experience, sludge at the inlet zone of the first aerated wastewater lagoon has to be removed at regular intervals of several years. To exhaust and take the sludge out, liquid manure-vacuum-tankers are used. Floating solids are retained by a scum board in the inlet area. They should be removed once or twice a week with a rake.

Oxidation Ponds

Oxidation Ponds are also known as stabilization ponds or lagoons. They are used for simple secondary treatment of sewage effluents. Within an oxidation pond, heterotrophic bacteria degrade organic matter in the sewage to produce cellular material and minerals. The production of these supports the growth of algae in the oxidation pond. Growth of algal populations allows further decomposition of the organic matter by producing oxygen. The production of this oxygen replenishes the oxygen used by the heterotrophic bacteria. Typically oxidation ponds need to be less than 10 feet deep in order to support the algal growth. In addition, the use of oxidation ponds is largely restricted to warmer climate regions because they are strongly influenced by seasonal temperature changes. Oxidation ponds also tend to fill, due to the settling of the bacterial and algal cells formed during the decomposition of the sewage. Overall, oxidation ponds tend to be inefficient and require large holding capacities and long retention times. The degradation is relatively slow and the effluents containing the oxidized products need to be periodically removed from the ponds.

Karnal Technology

The Karnal Technology involves growing trees on ridges 1m wide and 50 cm high and disposing of the untreated sewage in furrows. The amount of the sewage/effluents to be disposed of depends upon the age, type of plants, climatic conditions, soil texture, and quality of effluents. The total discharge of effluent is regulated so that it is consumed within 12–18 hours and there is no standing water left in the trenches. This technique utilizes the entire biomass as a living filter for supplying nutrients to soil and plants; irrigation renovates the effluent for atmospheric re-charge and ground storage. Further, as forest plants are to be used for fuel wood, timber, or pulp, there is no chance of pathogens, heavy metals, and organic compounds entering into the human food chain system, a point that is a limiting factor when vegetables or other crops are grown with sewage. Though most plants are suitable for utilizing effluents, yet, those tree species which are fast growing, can transpire high amounts of water and are able to withstand high moisture content in the root environment, are most suitable for such purposes. Eucalyptus is one such species, which has the capacity to transpire large amounts of water, and remains active throughout the year. Other species suitable for this purpose are poplar and leucaena. Out of these three species, eucalyptus seems to be the best choice as poplar remains dormant in winter and thus cannot bio-drain effluent during winter months. However, if area is available and the volume of effluent is small, a combination of poplar and eucalyptus is the best propagation. This technology for sewage water use is relatively cheap and no major capital is involved. The expenditure in adopting this technology involves the cost of making ridges, cost of plantation, and their care.

This system generates gross returns from the sale of fuel wood. The sludge accumulating in the furrows along with the decaying forest litter can be exploited as an additional source of revenue. As the sewage water itself provides nutrients and irrigation ameliorates the sodic soil by lowering the pH, relatively unfertile wastelands can be used for this purpose. This technology is economically viable as it involves only the cost of water conveyance from source to fields for irrigation and does not require highly skilled personnel. This technology seems to be the most appropriate and economically viable proposition for rural areas as it is used to raise forestry, which would aid in restoring the environment and generating biomass.

Duckweed

Duckweeds (aquatic plants) are the world's smallest and simplest flowering plants. Duckweeds are floating plants that grow on the surface of still or slow moving waters during warmer weather. Because duckweeds usually reproduce by budding, they can multiply very quickly and cover the entire surface of a pond in a short span of time. Small numbers of duckweeds will not harm a pond, but large numbers will block sunlight from entering the pond and upset the oxygen balance in the pond, placing the fish population in danger. *Lemna* spp. are the most common duckweeds. *Lemna* grow up to 4 mm wide and have a single root dangling from the leaf of the plant. Duckweeds do not have true leaves or stems; the roundish, flattened leaf-like part of the plant is called a frond. Another type, watermeal (*Wolffia* spp.), is the smallest of the duckweeds. These plants are so tiny that they look like grains of green meal floating on the water surface. They are generally less than 1 mm wide and barely visible as individuals. This type of duckweed does not have roots. Many a time control is necessary because the duckweeds reproduce rapidly and can cover a pond causing oxygen problems.

Fluidized Bed Reactor

Aerobic fluidized bed reactors (FBRs) are used as a new technology in wastewater treatment. An aerobic fluidized bed reactor with granulated activated carbon (GAC) as carrier material can be operated under different conditions, including batch-loading, semi-continuous loading, and continuous loading. The basic idea behind the FBR is to have a continuously operating, non-clogging bio-film reactor which requires: (i) no back-washing, (ii) has low head loss and (iii) high specific bio-film surface area. This is achieved by having the biomass grow on small carrier elements that move with the liquid in the reactor. The movement within the aerobic reactor is generated by aeration. These bio-film carriers are made of special grade plastic density close to that of water. The FBR employs fixed film principle and makes the treatment process more user friendly because it does not require sludge recycle that is, synonymous with conventional Activated Sludge Process. The absence of sludge recycle frees the operator from the enormous task of measurement and monitoring MLSS levels in the tank and adjusting recycle rations continuously, due to fluctuating inlet Chemical Oxygen Demand (COD) loads. The FBR produces small quantity of sludge which requires no further treatment. This technology is used in small STPs for treating city wastewater, industrial sewage treatment plant from food waste, paper waste and chemical waste etc. Due to fixed film nature, these plants accept shock loads much better than those employed for suspended growth process. The reactors are generally tall (6 m and above), thereby reducing cross-sectional area further.

Sequential Batch Reactor

In this process, the raw sewage, free from debris and grit, is taken up for biological treatment to remove organic matter, nitrogen, and phosphorus. The activated sludge bio-system is designed using the Advanced Cyclic Activated Sludge Technology which operates on extended aeration activated sludge principle for the reduction of carbonaceous BOD, nitrification, denitrification as well as phosphorus removal using energy-efficient, fine bubble diffused aeration system with automatic control of air supply based on oxygen uptake rate.

In this form, the sequences of fill, aeration, settle, and decant are consecutively and continuously operated in the same tank. No secondary clarifier system is required to concentrate the sludge in the reactor. The return sludge is recycled and the surplus is wasted from the basin itself. The complete biological operation is divided into: (i) fill-aeration (ii) settlement, and (iii) decanting. These phases in a sequence constitute a cycle. During the period of a cycle, the liquid volume inside the reactor increases from a set operating bottom water level. During the fill-aeration sequence, the mixed liquor from the aeration zone is recycled into the selector. Aeration ends at a predetermined period of the cycle to allow the biomass to flocculate and settle under quiescent conditions. After a specific setting period, the treated supernatant is decanted, using a moving weir decanter. The liquid level in the reactor is so returned to bottom water level after which the cycle is repeated. Solids are separated from the reactor during the decanting phase. The system selected is capable of achieving the following: (i) bio-degradation of organics present in the wastewater by extended aeration process; (ii) oxidation of sulphides in the wastewater; (iii) co-current nitrification and denitrification of ammonical nitrogen in the aeration zone; and (iv) removal of phosphorous

Tertiary Treatment

Tertiary wastewater treatment is employed when specific wastewater constituents which cannot be removed by secondary treatment must be removed. The treatment processes are necessary to remove nitrogen, phosphorus, additional suspended solids, refractory organics, heavy metals, and dissolved solids. Because advanced treatment usually follows high-rate secondary treatment, it is sometimes referred to as tertiary treatment. However, advanced treatment processes are sometimes combined with primary or secondary treatment (for example, chemical addition to primary clarifiers or aeration basins to remove phosphorus) or used in place of secondary treatment (for example, overland flow treatment of primary effluent).

Control of Pollution: Legal and Institutional Provisions to Control Pollution

The Water (Prevention and Control of Pollution) Act 1974 and The Environment Protection Act 1986

The government enacted the Water (Prevention and Control of Pollution) Act 1974 with the primary objective of prevention and control of water pollution and restoration of water quality. The Central and

State Pollution Control Boards were established for its implementation. The Water Act empowers the pollution control boards to lay down and maintain water standards. The actual provisions for enforcement such as penalties, imprisonment etc. are largely confined to source-specific standards for individual polluters. The Environment Protection Act, 1986 is an umbrella act providing for the protection and improvement of the environment and for matters connected therewith. It authorizes the central government to intervene. The nature of penalties allowed under this act are similar to those authorized under the Water Act.

The Environment Protection Act, 1986 covers hazardous wastes and chemicals, hazardous microorganisms, and transportation of toxic chemicals. Supported by recent legislative, administrative, and judicial initiatives, environmental regulations in India are becoming more comprehensive. The licensing regime is supplemented by a 'citizen suits' provision and besides, a statutory 'right to information' now enables an aggrieved citizen to directly prosecute a polluter after examining the government records and data. Rules have been notified for environmental auditing of all the industries which may cause water pollution or generate solid or hazardous wastes. The Ministry of Environment and Forests has adopted a 'Pollution Abatement Policy' which includes adoption of clean technology, conservation of resources, change of concentration-based standards to mass-based standards, incentives for pollution control, public participation, environmental auditing, and Eco-mark on environment friendly products.

The legal and institutional provisions are provided in Water (Prevention and Control of Pollution) Act, 1974 wherein standards are developed and enforced for treatment of municipal wastewater by pollution control boards. There are provisions for tightening of standards by state pollution control boards for site-specific requirements, in view of low flow or no flow in stretches of rivers or streams and for critically polluted areas in view of high concentration of pollution loads in a specific area. The need based directions for zero discharge are prescribed for grossly polluting industrial units; however, such enforcements are non-implementable in case of municipal bodies. The concept of delinking of sewer to river is gaining momentum in river conservation plans and may bring about a visible improvement in water quality of recipient water bodies. There is, however, a need for institutional provisions to make the rivers and streams perennial by introduction of minimum/environmental/ecological flows to maintain the biodiversity and sustainable ecosystem of aquatic resources.

Conclusion and Outlook

There is a need to generate water from all available resources including wastewater by recycling, reuse, recharging, and storages. There is urgent need to plan strategies and give thrust to policies giving equal weighting to augmentation of water supplied as well as development of wastewater treatment facilities.

Municipal wastewater collection, treatment, and disposal are still not a priority by the municipality/state government as compared to water supply. In the absence of sewer lines, untreated wastewater is flowing into storm water drains and poses health hazards to the citizens inhabiting the areas near the drain. The O&M are not satisfactory due to lack of proper power supply/backup power; municipal authorities do not have the money for spares and payment of electricity bills; there is a lack of skilled manpower and most of the plants are under-loaded due to lack of proper sewer lines.

Although municipal wastewater treatment is given impetus under National River Conservation Plan of Ministry of Environment and Forest, Government of India to provide sewage treatment plant to cities discharging wastewater to rivers, in spite of all these effort and various schemes, the gap between generation and treatment is still large.

There are various issues with treatment technology in addition to management aspects. The primary requirement for wastewater treatment is adequate supply of electricity which is a deterrent in the present context in almost all the states of the country. Treatment technology selection for different sizes of urban settlements is another issue due to the constraint of land availability.

The waste stabilization ponds (oxidation ponds, maturation ponds, and duckweed ponds) are most appropriate for small towns having land availability for treatment plants and demand for treated wastewater in agriculture. In large urban settlements with land scarcity for the establishment of STPs and less demand for treated sewage for farm application, mechanical treatment systems viz. activated sludge process, trickling filter, UASB, and aerated lagoons are appropriate and produce good results. There are success stories of treatment plants producing reasonably good quality water which is being used in the industrial sector for processes as well as cooling purposes thereby reducing the industrial demand for fresh water.

References

Afifi, Ahmed A., Kh. M. Abd El-Rheem, and Refat A. Youssef (2011), 'Influence of Sewage Water Reuse Application on Soil and the Distribution of Heavy Metals', Nature and Science, Vol. 9, No. 4, pp. 82–8.

Bhardwaj, Rajendra M. (2005), 'Status of Wastewater Generation and Treatment in India', Paper presented at Intersecretariat Working Group on Environment Statistics (IWG–Env) Joint Work Session on Water Statistics, Vienna, 20–22 June.

Blumenthal, Ursula J., Anne Peasey, Guillermo Ruiz-Palacios, and Duncan D. Mara (2000), 'Guidelines for wastewater reuse in agriculture and aquaculture: recommended revisions based on new research evidence', Study Published by London School of Hygiene and Tropical Medicine WELL Study, Task No. 68, Part 1, UK.

Bradford, Andrew, Robert Brook, and Chandra Hunshal (2003), 'Wastewater Irrigation: Hubli-Dharwad, India', Paper presented at International Symposium on Water, Poverty, and Productive uses of Water at the Household Level, 21–23 January, Muldersdrift, South Africa.

Grover, Mukesh (2011), 'Degrémont Water Treatment Technologies and A Case study of 635 MLD WTP at Sonia Vihar–Delhi', presented to working group of Planning Commission on Working Group on Urban and Industrial Water for Twelfth Plan of Government of India.

Mara, D. (2009), 'Design Manual for *Waste Stabilization Ponds* in India', University of Leeds, England, available at http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/wspwarm/wspwarm.html Last accessed in June 2011.