Wastewater Management to Environmental Materials Management 111

Musarrat Parween and A. L. Ramanathan

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M. Parween (✉)
Water Programme, National Institute of Advanced Studies, Bengaluru, Karnataka, India

A. L. Ramanathan
School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India

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Abstract

Drinking water and sanitation has been recognized as the prioritized area of global development, but this sector is also coupled with enormous loads of wastewater generation. The challenges associated with wastewater management thus seem to be ever growing. Wastewater management is a key player in achieving future world water security, and the issues concerning wastewater and water quality have deep rooted connections with various other issues but not limited to the water, food, and energy-nexus. Inadequate/inefficient wastewater management can pose severe threats to ecosystems, human health, and economic activities too.

In this context, the current wastewater management scenario in the world has been elaborated in order to identify and understand the shortcomings of this sector. The reasons that have deprived most of the cities of adequate wastewater management are numerous such as aging, absence or inadequacy of sewage infrastructure, lack of wastewater disposal and treatment facilities, technological failure, ineffective operation, lack of maintenance, and so on.

Wastewater management not only needs immediate attention on a priority basis but should also be considered as merely a part of an integrated, full life cycle-based and ecosystem-based management system that encompasses all the dimensions of sustainable development. This calls for a shift from an isolated “wastewater management” to the “materials management” approach.

This approach emphasizes on the importance of the association between demands/consumption patterns and wastewater generation, and also accentuates on waste reduction throughout the production process. Environmental Materials Management (EMM) is largely being recognized as basically a policy approach which has a significant potential to attain green growth. EMM would be largely beneficial for the economy, environment, and employment related perspectives. Its policy principles will lead to the preservation of natural resources and/or capital, exercise of policy instruments, life cycle outlook, and multistakeholder approach.

Keywords

Water security · Water quality · Life -cycle · Ecosystem · Integrated approach · Materials management · Wastewater · Surface water · Ground water · Agriculture · Irrigation · Industry · Domestic sewage · Municipal wastewater · Pollution · Human health · Health risk · Food security · Infrastructure · Modern technology · Water management · Environmental management · Wastewater management · Ecosystem-based management · Green growth · Natural resources · Efficient use · Wastewater reuse · Recycle · Recovery · Conservation ·

Policy · Economy · Employment · Multidimensional approach · Multistakeholder approach · Multisectoral perspectives · All inclusive · Participatory approach · Community empowerment · Institutional integrity

Introduction

Water is life and an indispensable component of everyday activities of every individual. It not only serves human needs at individual levels for several purposes like, drinking, bathing, washing, cooking, etc., but also drives life into agriculture and industries. It also helps in the disposal of wastes at all levels. Water bodies have been used since the age of ancient civilizations for the purpose of diluting wastes from all sources. This has now reached an extent where the dilution capacity of rivers, streams, and lakes has been overtaken by the pollution load from the overgrowing population and intensifying industrialization. Numerous rivers and lakes, especially in the vicinity of urban settlements have been strangled to death, while the others are on the verge of dying. On the other hand, overextraction of groundwater, essentially for agriculture, has led to a state where geological contamination of groundwater has become a curse in several parts of the world. Unfortunately, these are also the only sources of water for drinking. Drinking water quality has turned out to be a major concern worldwide. The unplanned use and extraction of water, rising food security concerns, expanding industrialization, improper waste discharge, as well as lack of proper and sufficient means and mechanisms of wastewater treatment have left the future water security concerns soaring.

An awful figure of about one person among every five in the world does not have access to safe and affordable drinking water. More than half of the world's population does not have access to sanitation facilities. Approximately two billion people around the globe use a source of drinking water contaminated with feces. More than eight million people die each year from waterborne diseases, which includes more than 3.6 million children under 5 years of age who die of diarrhea, as per the World Health Organization statistics (WHO 2017). Several other studies have reported even higher numbers of deaths each year. Water holds a key position among the sustainability challenges facing human (Falkenmark and Rockström 2004; Sivapalan et al. 2014).

Water is an invaluable resource that is available unevenly in time and space through different parts of the world, which is determined by several factors such as geography, terrain, geology, land use pattern, and so on. Despite the world using hardly a small fraction of renewable water resources, there exists large special diversity in this fraction. It is extremely higher and lies in the range of 80–90% in several of the arid and semiarid river basins which makes it scarce in such regions.

Approximately 500 million people in the world inhabit regions (certain parts of India, China, the Mediterranean region and the Middle East, Central Asia, arid parts of sub-Saharan Africa, Australia, Central and Western South America, and Central and Western North America) which are characterized by the extent of water consumption rising greater than twice as much as the locally available renewable water resources (Connor et al. 2017). Transportation of water to such water scarce regions from water surplus locations even for essential everyday activities has become a business as usual scenario in several parts of the world.

In several of the tropical river basins considerably large volume of water is available on an average almost over the year, but its uneven temporal distribution renders it usable. Huge and capital intensive infrastructure is required to protect people from such downpours and to store it preserved for later use. It bears enormous social and environmental impacts too.

It is therefore pertinent to understand the importance of water conservation and its judicious use. With the focus of the Millennium development goals on water and sanitation, without due consideration on managing the intensified wastewater, problems related to world water security and quality are expected to take a toll (UN-Water 2015). Wastewater management therefore has a major role to play in achieving future world water security (OECD 2012). The two have deep associations with several other issues concerning water, food, energy, ecosystem, and sustainability and therefore cannot be considered standalone.

Wastewater is generated globally by both point as well as nonpoint sources in the form of agricultural discharge, domestic or municipal as well as industrial wastewater. Agricultural discharge is the biggest contributor of wastewater, yet difficult to manage due to its diffused nature. However, it is much easier and feasible to tap and treat those from point sources, such as municipal as well as industrial wastewater. Data compiled from a variety of sources (FAO 2016; Sato et al. 2013) indicate a global figure of more than 330 km^3 $year^{-1}$ of wastewater (mainly municipal) generation. China, India, United States, Indonesia, Brazil, Japan, and Russia together contribute to more than 167 km^3 of wastewater alone, which amounts to more than half of the global municipal wastewater produced per year.

Wastewater has the prospective of being used in several developmental processes ranging from the use of grey water for flushing to that of untreated domestic wastewater for gardening, determined largely by the type of wastewater and the intended use. Wastewater and sludge is laden with numerous valuable resources such as water, energy, organic matter, and nutrients like nitrogen and phosphorus, etc., which can be diverted for their use in several other economic, social, and environmental activities (Parween et al. 2017). Nevertheless, insufficient data are available globally on wastewater flows and their qualities limit such applications and management practices by and large. Literature concerning wastewater discharge/generation is therefore the prime requirement in the current situation. However, some recent data concerning the same has been made available with the help of global efforts by FAO/IWMI, UN-Habitat (2008), and the Global Water Intelligence (GWI) 2014.

The average of wastewater treated globally according to AQUASTAT depicts a good figure reflecting treatment of 60% of the produced municipal wastewater. However, this figure could be misleading keeping in account the fact that several waste treatment plants are not functional, partially functional or underutilized in many of the developing countries, while data from some of the low-income countries important in this aspect remains unavailable. According to Sato et al. (2013) the percentage of wastewater that is treated ranges from an average of about 70% to merely 8% respectively in high- and low-income group of countries. Moreover, treatment of the wastewater is often not accomplished up to the desired level. Wastewater that require treatment up to the secondary or tertiary levels are often left partially treated up to only primary or secondary levels respectively in most of the low-income countries. Above all, proper and systematic channeling as well as maintaining the segregation of treated as well as untreated wastewater is yet another flaw in the existing management systems of some parts of the world. Mixing of treated and untreated wastewater is a futile as well as uneconomic activity which should be strictly controlled.

Treatment of wastewater indisputably comprises of an essential step towards meeting the world water security as well as the prevention of contamination of aquifers, but is not the only measure that needs attention in this regard. Wastewater treatment should rather be considered as an indispensable part of an integrated approach towards wastewater management which essentially undertakes a materials management approach considering full life cycle-based, ecosystem-based management model operable across all the three dimensions of sustainable development (social, economic, and environmental), irrespective of geographical boundaries, local barriers, localized sociopolitical motives in consideration to both water and wastewater. The pillars of this materials management approach are based on the keys of reduce, reuse, recycle, as well as recover. Therefore, the materials management approach begins with the judicious use of water and spreads across conservation and management at every stage by switching to products, services, and processes that are lesser water intensive and/or facilitate sustainable use of water. It also includes several other components such as, treatment, recycling, reuse, recovery of essential components, wise and efficient disposal of nonutilizable or residual wastes, facilitation of aquifer-recharge, prevention of pollution of other water bodies, promotion of social awareness and community participation as well as their empowerment, and so on. Society has a vital role to play in wastewater materials management. The manner in which materials are being used in a society has an impact on the economy as well as the environment. Efficient and judicious use of materials by way of cutting down on raw materials, efficient designing, marketing, reuse, recycling, and disposal mechanisms can not only help meeting our needs but also sustaining the process.

This chapter aims at providing an overview on various aspects of water use, wastewater, its generation, as well as treatment in a global context. An elaborate account of latest facts and information concerning status and strategies of wastewater treatment and management worldwide has been used to highlight the need of an integrated wastewater management approach, more precisely the materials management approach towards wastewater management, which is the need of the current situation. The various aspects that need to be covered under the wastewater materials management approach have also been described in details.

Water Demand, Wastewater, and the World

Rising World Water-Demand

Water crisis was considered as as the global risk of highest concern for people and economies for the next 10 years (WEF 2015). A projected rise in the overall world water demand by 55% is expected by 2050 from that of 2000 taken as the baseline, including an increase in demand by 400% in the manufacturing sector, 130% in the domestic sector, and 140% for electricity generation, leaving the irrigation sector behind to see a decline of consumption by 14% (Mountford 2011). Studies have also predicted a global water deficit of 40% by the year 2030 with the business as usual scenario (2030 WRG 2009).

Wastewater

An Overview

Wastewater according to Corcoran et al. (2010) can be defined as one or more of the following:

(i) Domestic effluent which consists of black-water (excreta, urine, and fecal sludge) and grey-water (kitchen and bathing wastewater)
(ii) Discharges from commercial institutions such as schools and hospitals
(iii) Industrial effluent, storm-water, and other urban runoff
(iv) Effluents from agricultural, horticultural, and aquaculture (dissolved or suspended matter)

Wastewater can therefore be demarcated as domestic (fecal and non-fecal), commercial, industrial, and agricultural based on sources as well as chemical composition which makes each of the type distinct from the other.

Wastewater and Its Impact on Water Quality and Health

Wastewater is constituted of approximately 99% water and 1% suspended, colloidal, and dissolved solids (UN-Water 2015). This makes it a potential contender in contributing to future world water security. However, another key factor which makes it pertinent to be managed is its potential threat to health and environment otherwise, which can have serious social and economic implications (e.g., increased treatment costs to make water usable for certain purposes). The various kinds of pollutants that are the components of wastewater can be listed as following:

(i) Organic pollutants (proteins, carbohydrates, fats, nucleic acid, etc.)
(ii) Inorganic nutrients (nitrogen, phosphorus, potassium)
(iii) Pathogenic microorganisms (bacteria, viruses, protozoa, and helminths)
(iv) Toxic metals (cadmium, chromium, lead, mercury, copper, nickel, zinc, arsenic, selenium, etc.)

(v) Synthetic organic compounds (synthetic pesticides, polychlorinated biphenyls, poly-aromatic hydrocarbons, synthetic detergents, food additives, pharmaceuticals, cosmetics, paints, oils, synthetic fibers, plastics, etc.)
(vi) Thermal and radioactive pollutants (radioactive isotopes of uranium, strontium, iodine, phosphorus, cobalt, strontium, etc.)

Agricultural Discharge and Runoff

Discharges from agricultural fields are often enriched with nutrients such as, potassium, phosphorus, nitrogen, etc. The runoff gets enriched with such nutrients owing to the application of fertilizers and manures on the field crops for enhanced productivity. These nutrient-laden wastewater in the form of runoff reach water bodies and lead to their eutrophication.

Eutrophication of streams, lakes, and ponds have not only resulted in the loss of primary productivity of such ecosystems abut have also led to extensive deterioration of biodiversity worldwide. The world's wetlands are reduced to half in the twentieth century, depicting significant loss of biodiversity (Cosgrove and Rijsberman 2000). Eutrophication is responsible for reducing one third of the world's wetland biodiversity and have impacted severely countries such as China, Europe, Japan, South Asia, and Southern Africa. The non-OECD countries are expected to see a further deterioration in water quality in coming decades owing to the rise in agricultural discharge of nutrients and poor status of wastewater treatment. The lakes are expected to be affected by algal blooms higher by 20% within a few years (OECD 2012).

Apart from nutrients, chemicals such as, insecticides, herbicides, growth enhancers, and other agrochemicals used in farming can also be serious threats to several ecosystems. Most of these compounds are xenobiotic and bioaccumulate within food chains (Parween et al. 2014). These are detrimental to the health of living organisms and have even resulted in the extinction of several species of ecological importance. Microbial runoff from the excreta of livestock too can be a serious issue originating out of agricultural runoff. Within the OECD countries, agriculture which is considered to be a nonpoint source of pollution is playing a major role in inland and coastal eutrophication, taking over the quantum of contribution by the point sources of pollution (FAO 2012). Another problem associated with agricultural runoff is siltation due to sediment deposition from runoff at locations that lead to flooding of the streams.

Domestic Wastewater, Storm-Water, and Urban Drainage

Domestic wastewater, a mix of grey water and black water in variable proportions, is often laden with excreta which carry pathogenic microorganisms. Diarrhea is the cause of death of around 1.45 million people annually, mostly children (48%), essentially caused due to poor availability of water and hygiene (58% of all causes).

The composition of domestic wastewater is largely determined by the availability of water supply and sanitation measures, practices of using water and social standards. Around half of the world's population is deprived of appropriate means of disposing off sanitary wastewater from toilets, and more than half from disposing greywater from kitchens and baths (Laugesen et al. 2010).

Runoff in the form of surface water and storm-water from cities and urban habitations is a massive and an emerging problem that needs immediate attention. Inadequate design and infrastructure available for the drainage of such discharges, especially in towns and cities, have often lead to the conditions of floods and clogs. The problem intensifies in cities with open channel surface water drains, especially in the developing countries, which are devoid of sanitary sewers. These open channels are hazardous to human health as these also contain solid waste and wastewater.

Urban surface water has become a challenge not only in the developing, but also the developed countries. Technical developments in order to encounter this have been under progress since several decades, the most recent being the sustainable urban drainage systems.

Industrial Wastewater

Industrial wastewater can be broadly distinguished on the basis of discharge as localized and diffuse. While localized wastewater represents effluents with fixed outlets, diffuse discharges are those that arise from activities such as mining, quarrying, and agro industries, which are usually very toxic or hazardous. Collection, reclamation, and control via regulation of localized industrial discharge are therefore feasible processes provided social, economic, as well as political support.

Industrial wastewater may be laden with several kinds and classes of pollutants. Toxic metals may be released from industries such, as mining, metal, textile, dying, printing, power plants, etc. Power or energy-based industries also lead to thermal pollution which is a threat to ecosystem productivity and biodiversity. Industries related to mining, chemicals, and biomedical sectors are responsible for the generation of radioactive pollutants.

Industries are also the major pollutants of synthetic organic compounds. Chemical and agrochemical industries produce synthetic pesticides, polychlorinated biphenyls, synthetic detergents, etc. Food and pharmaceutical industries lead to release of food additives and pharmaceuticals, while others such as cosmetics, paints, oils, synthetic fibres, plastics, etc. release numerous toxic chemicals in the environment. Poly-aromatic hydrocarbons are a group of carcinogenic compounds that are most often released due to combustion of coal and carbon-rich fossil fuels from power based industries.

Global Water Consumption and Wastewater Generation

The WaterGAP3 model in 2010 depicted the global annual domestic water withdrawals which accounted to 390 km^3 (Flörke et al. 2013) compared to the figure of 477 km^3 obtained by Shiklomanov way back in 2000. The global production of wastewater together by the domestic and the manufacturing sectors as estimated by

WaterGAP model further amounted to 450 km^3 in 2010, and 315 km^3 which comprises of around 70% alone by the domestic sector (Flörke et al. 2013).

Estimates made available from FAO's AQUASTAT indicates the rate of global freshwater withdrawals as 3,928 km^3 per year. Around 44%, i.e., 1,716 km^3 $year^{-1}$ of the water withdrawn is used, mainly in agriculture essentially, through evaporation in irrigated crop fields. The remaining 56% (2,212 km^3 per year) is discharged as wastewater, mainly in the form of effluent from municipal and industrial sectors as well as agricultural drainage FAO (2016).

It has been estimated that an average of around 70% of the total wastewater generated by the developed (high-income) countries is being treated. The figure stands to 38% for the mid-income countries, drops down to 28% low-mid-income countries, and remains as low as merely 8% in low-income countries (Sato et al. 2013).

Where on one hand, developed countries with high per capita income are technologically well equipped and have the means to invest more in the sector of wastewater treatment, the middle- and specifically the low-income countries find it difficult to afford such expensive treatment systems. By and large, the rising populations of the latter countries keep contributing to the substantial growth in wastewater generation which supersedes the developments made in the facilitation of wastewater treatment, thereby upholding the lower ratios of wastewater treatment to wastewater generation.

Data compiled by other sources namely those by AQUASTAT (FAO 2016) and Sato et al. (2013) indicates that the worldwide production of municipal wastewater is greater than 330 km^3 $year^{-1}$. As stated earlier, more than 167 km^3 that accounts for half of the global municipal wastewater production was estimated to be produced together by China, India, United States, Indonesia, Brazil, Japan, and Russia.

Wastewater Treatment Process

Wastewater is generally collected by the municipalities through piped system or sewerage, and is named as "sewage." It may then be subjected to the process of treatment up to various levels such as, primary, secondary, and tertiary which may be determined by the type, composition, and targeted posttreatment usage of wastewater (Table 1). A systematic diagram depicting the chain of municipal management of wastewater from generation to its fate is represented in Fig. 1. This clearly demonstrates that only a small fraction of wastewater which is actually treated is being used judiciously. There are failures associated with every stage of wastewater treatment right from collection to posttreatment channeling and discharge, which will be elaborated in the sections following.

Wastewater Treatment Scenario

An average of approximately 60% of the world's municipal wastewater is treated according to the data available from AQUASTAT (FAO 2016). However, this figure

Table 1 Stages of wastewater treatment

Wastewater treatment process		
Stages	Purpose	Methods
Pretreatment/ screening	Removal of grit, grease, and large solids	Screening, filtration
Primary treatment	Settling and removal of suspended solid materials: organic and inorganic in nature	Primary settling tanks, centrifugal separation, sedimentation and gravity separation, coagulation, flotation
Secondary treatment	Removal of soluble organics with the help of microbial decomposition (aerobic or anaerobic)	Aerobic and anaerobic processes: activated sludge, trickling filters, oxidation ponds, aerated lagoons, anaerobic sludge blankets
Tertiary treatment	Removal of nutrients such as, nitrogen and phosphorous, trace metals, toxic compounds, residual suspended matter, pathogenic microorganisms	Distillation, evaporation, crystallization, oxidation, precipitation, ion-exchange, chlorination, ozonation, ultraviolet radiation, adsorption, reverse osmosis, adsoprtion, microfiltration, nanofiltration, ultrafiltration

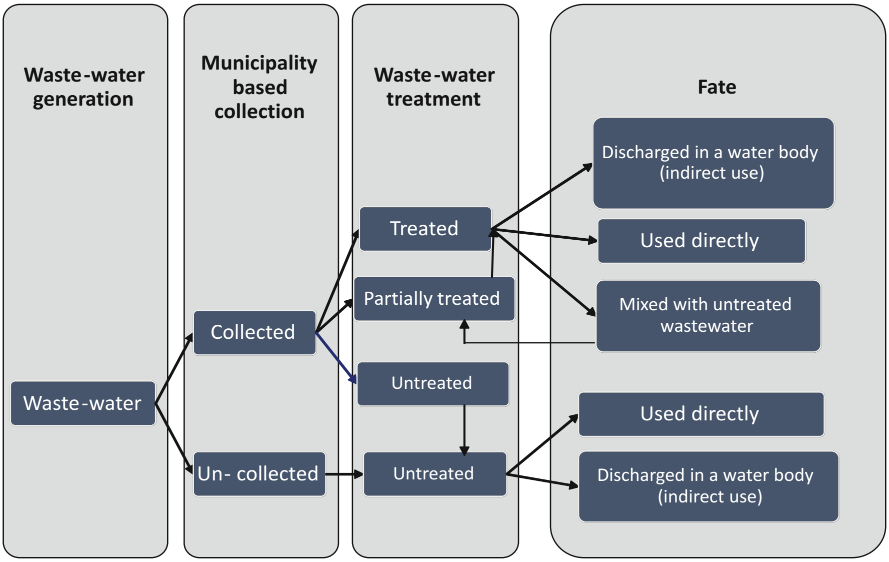

Fig. 1 Municipal wastewater treatment process

is expected to be substantially lower owing to the fact that the waste treatment plants are nonfunctional or underutilized in several countries, especially, the low-income countries (Massoud et al. 2009). Moreover, data from some of the large low-income countries is unavailable.

Compared to this data, the one corresponding to that of the global tertiary treatment and advanced reuse capacity is documented relatively better and accounted to 24 km^3/year in 2014 (GWI 2009). The wastewater treatment capacity has been observed to be strongly correlated with the income status of countries concerned, which is obviously higher in case of the high-income countries as compared to those of the low-income countries. The average percentages of wastewater treated are 70%, 28%, and 8%, respectively, in high-income, lower-middle income, and low-income countries (Sato et al. 2013). Variation in the extent of wastewater treatment could be observed not only within countries but also within cities of a different country with respect to their development (Raschid-Sally and Jayakody 2008). Cities in developing countries are often not well equipped with facilities of wastewater collection as well as treatment as against the cities within the developed countries which are technologically as well as infrastructural better off.

Prospective Uses of Wastewater

While the direct use of treated wastewater implies its use in various sectors, such as crop irrigation, gardening, forestry, industrial processes, etc., as such; its indirect use applies to its dilution by discharge into water bodies such as rivers before such applications. Where direct uses are often planned, indirect uses after dilution are not planned.

The declining availability of water itself is the factor which has triggered the use of wastewater in various forms. The usage and its extent, be it with or without treatment, are determined largely by the social, economic, political, and cultural environments. The common usages, however, have been enumerated in Table 2 under section "uses of wastewater."

Table 2 Examples of wastewater uses in various sectors

Uses of treated and untreated wastewater	
Sector	Uses
Agriculture	Irrigation of crops, vegetables, edible gardens, pasture for livestock
Landscape	Commercial nurseries, parks, residential, corporate and commercial gardens (flower gardens, desert gardens, rock gardens, etc.) and lawns, hospital and school yards, freeway golf course, cemeteries, city forests, greenbelts, roadside plantation, bushes, and fences
Industrial	Water as a coolant, water in boilers, industrial processes, concrete mixing, and construction activities, etc.
Hydrogeology	Groundwater recharge, reduction in saltwater intrusion
Ecological and recreational	Feeding lakes and ponds, development of marshes, wetlands and sanctuaries development, stream-flow augmentation, fisheries, snowmaking, ice-skating floors
Nonpotable	Fire fighting, air conditioning, commercial fountains, toilet flushing
Potable reuse	Washing of vehicles, blending in water supply reservoirs, pipe-to-pipe water supply

Wastewater Usage: World Scenario

While developed countries use wastewater in a more planned and organized way, extensive informal use of wastewater, mostly untreated, has been documented in lower-income countries where wastewater collection and treatment cannot be accomplished with a large coverage and/or in a systematic manner. The informal use of wastewater is probably ten times more than that of formal reuse (Scott et al. 2010). Wastewater is used as an alternative in countries with arid or semi-arid regions where water availability is limited or those with dry seasons where availability is restricted to the wet months. Remote regions which lack affordability for extracting or transporting water to the desired locations in such circumstances often see the use wastewater as a substitute, especially for agriculture (Parween et al. 2017). Highly saline and contaminated (such as by fluoride, arsenic, nitrate, etc.) existing sources of water could be another reason stimulating such informal uses. Unofficial documentation of the use of wastewater in urban and peri-urban regions of several developing countries have been evident from literature (Parween et al. 2017; Raschid-Sally and Jayakody 2008; WHO 2006). Among the several cases that have been reported throughout the world a few included from Asia and Africa have been mentioned as examples. Farms in Pakistan have been using untreated wastewater owing to the excessive salinity of treated wastewater as well as the available groundwater in the region (Ensink et al. 2002). Wastewater from open and underground sewers are being used by farmers for irrigation in Hobli, Dharwad, the semi-arid regions of Karnataka in India (Bradford et al. 2002) because it is cost-free as against borewell water which is chargeable (Mateo-Sagasta et al. 2015).

Cities such as, Haroonabad in Pakistan and Delhi, Varanasi and Hyderabad in India which have wastewater as the only flowing material in the canals that are used for irrigation during the dry months have witnessed agricultural use of wastewater in the absence of other alternatives (Ensink 2006; Parween et al. 2017; Singh et al. 2010). Sewage lines are even intentionally ruptured in order to use wastewater such as those in Nairobi (Kenya), Bhaktapur in the Katmandu Valley (Nepal), and Dakar in Senegal (Hide et al. 2001; Rutkowski et al. 2007; Faruqui et al. 2004; Mateo-Sagasta et al. 2015).

Researchers have also reported the use of wastewater from broken treatment plants or sewers avoiding the trouble of collection at the end of the farmers especially in Cochabamba of Bolivia, Accra and Tamale of Ghana (Huibers et al. 2004; Abdul-Ghaniyu et al. 2002). There are reports of planned blockage of sewage in Addis Ababa (Ethiopia) and Maili Saba (Kenya) so that raw sewage can rise up the manholes and reach farm land by overflowing (Hide et al. 2001; Mateo-Sagasta et al. 2015).

Apart from being used directly, the indirect use, which is the most extensive use of wastewater (Jimenez and Asano 2008; Keraita et al. 2008; Scott et al. 2010), has been influencing human health to a large extent in several parts of the world, especially those with dry and wet climatic conditions. Wastewater is discharged into freshwater streams, which after dilution is accessible downstream for domestic, agricultural, and industrial needs. This wastewater in middle- and low-income countries is often untreated. Reports have been documented from several parts of the world, such as, Africa, India, Nepal, China, Argentina, Brazil, Colombia, etc. (Keraita et al. 2008; Parween et al. 2014; Jin et al. 2005; Jimenez 2008; Raschid-Sally and Jayakody 2008).

Extensive irrigation of vegetables with polluted water has been reported in the vicinity of cities in west-Africa, India, and China (Drechsel et al. 2006; Parween et al. 2014; Khan et al. 2008).

In contrast to this condition, high-income countries, such as those in the Middle East and North Africa, Australia, USA, and the Mediterranean (FAO 2014; GWI 2009), often value the water present as a resource in wastewater and plan the management of treated wastewater in a systematic manner. Despite being self-sufficient in water supply, some countries reclaim wastewater as it essentially helps preserving other freshwater ecosystems. Windhoek of Namibia deserves to be mentioned specifically as an example (Lahnsteiner et al. 2013). However, acceptability for the reuse of reclaimed wastewater continues to remain a challenge.

It should therefore be noted that interferences with wastewater management do exist irrespective of the practices (good or bad) or income status of the country (low-income or high-income countries). Wastewater management should essentially be a holistic approach which not only includes collection, treatment, good and wise practices but also awareness, social acceptability, public participation, etc., and several other aspects. The next section provides an elaborate discussion on the need of an integrated approach towards wastewater management.

Waste Water Management: The Need of an Integrated Approach

With improved sanitation as the prime target of the Millennium Development Goals, collection, treatment, discharge, and use of wastewater have not been able to draw attention that it deserved. Urban population of the world is expected to double in 40 years and reach above six billion. However, there has been little attention on the status of wastewater management which is obviously going to take a dreadful shape, if not attended. Poorly maintained, aging and inappropriate or inadequate sewage infrastructure are typical to most of the world's cities (World Water Council 2012). As per the fourth World Water Development Report, merely 20% of the wastewater generated globally is properly treated (UNESCO 2012). The need of bringing wastewater to the forefront in world water politics echoed in the World Water Forum meet, 2012.

This calls for a shift in world water politics to preserve further destruction of ecosystems and attend to wastewater as a rather useful resource, the management of which is crucial to future water security. The various aspects of water and wastewater are often seen as standalone and therefore remain fragmented in addressing a common cause. It is therefore pertinent to introduce integrated water resource management and wastewater management in order to take a holistic approach. See ► Chap. 75, "Role of Earthworms in Managing Soil Contamination"

The overall objectives of a complete and sustained development in association with wastewater management will be fulfilled only if an integrated approach towards wastewater management is adopted, with simultaneous actions in multiple dimensions in coordination with social, economic, and environmental sustainability and be concerned with not only wastewater, but switch to a concept of complete life cycle-based and ecosystem-based management of water. The management should be free from geographical boundaries and resource type and should therefore include water resources as undivided entities and include all of marine and fresh water as well as surface and ground water resources.

Environmental Materials Management (EMM) Approach

EMM-based approach towards wastewater management is basically associated with the efficient reduction of prevention of environmental deterioration while exercising a complete life cycle-based management of materials/resources concerned, which essentially extends across political and geographic boundaries and involves multiple disciplines as well as stakes. To practically achieve these goals is a great challenge and seeks coordination between various sectors and stakeholders. EMM would not only improve the environment by reducing the amount of resources that human economic activity requires but also minimize associated environmental impacts and improve resource security, growth, competitiveness, and job opportunities. It would therefore benefit the economy, environment, and employment by and large. See ► Chap. 3, "Decentralized Integrated Approach of Water and Wastewater Management in Rural West Bengal."

A carefully selected comprehensive and coherent array of policy instruments to contribute as policies along the different life cycle phases of materials is key to the EMM approach. A full life cycle approach would essentially take into consideration the trans-boundary nature of material flows and the diversity of economic actors. It also calls for coherence in policies among sectors and coordination across departments, governments, organizations, forums, boards, etc., at national as well as international levels. It is therefore pertinent to develop and strengthen partnerships and networks and facilitate capacity building for an effective EMM worldwide.

Therefore there are several measures and preparations that need to be undertaken in order to indulge into an EMM approach concerning wastewater management. Some of the important steps that can be essential in building up the concept have been listed as following:

Reuse of Treated/Untreated Wastewater

Though the domestic sector comprises of a small share of the total water consumption, water conservation could begin right from personal or family level uses such as, drinking, bathing, washing, cleaning, cooking, gardening, etc. In several countries, water which is fit for drinking is also used in toilet flushing, irrigating gardens and lawns, washing cars and floors, etc. Houses or apartment could be equipped with the facility of reusing grey water. Such practices need to be followed and imposed strictly by law in commercial institutions, such as school, hospitals, corporate houses, shopping complexes, etc. Various fields and sectors which have immense scope of untreated and treated water reuse have been listed in Table 2 under section "uses of wastewater."

Keeping the baseline figure of water consumption in 1995, a study conducted by IFPRI (Rosegrant et al. 2002) had projected a decline in the global water demand as against a figure of 4,772 billion m^3 under business as usual scenario to 3,743 billion m^3 if water is used sustainably by 2050.

Recycling/Recovery of Resources

Used water is often enriched with several useful resources. Extractable phosphorus which is a limited resource is predicted to become rare or exhausted in another 50–100 years (Van Vuuren et al. 2010). Wastewater therefore holds immense importance as an indispensable and alternative resource. It has been estimated that around 22% of global phosphorus demand could be fulfilled by recycling human urine and feces (Mihelcic et al. 2011).

Recovery of nitrogen and phosphorus from sewage or sludge demands advanced and sophisticated technologies, which is under progress but still in the developmental phase.

Recycling nutrients or extracting energy from wastewater also provides ample scope in terms of new opportunities of income generation and extends the resource availability to the deprived section of society. For example, "composting-toilets," which is a low-cost solution for enhancing agricultural productivity and nutrition while simultaneously reducing health and environmental impacts due to open defecation (Connor et al. 2017) is also a means of income generation for the local communities.

Efficient Use of Water

In several major cities of Asia and Latin America the total water produced by utilities is significantly high, ranging from 200 to 600 l per person per day. However, up to 70% of this is lost to leakages. Service as well as the quality of water are poor and erratic (Cosgrove and Rijsberman 2000). The major setbacks which lead to inefficient use of water are lack of political will and sufficient investment in water supply services and management of water resources. Lack of skilled as well as skilled manpower to manage these is also a significant hindrance.

Research conducted in several countries (Burkina Faso, Ghana, Laos, Mozambique, Niger, Papua New Guinea, Senegal, Sri Lanka, Tanzania) have revealed that they are subjected to a cumulative shortfall of 787,200 trained water and sanitation professionals in their way to achieve universal coverage in water and sanitation

(IWA 2014). Twenty-seven out of the 67 countries had sufficient staff to operate and maintain their urban drinking water systems, while merely 11 had the same for their rural drinking systems. The supply of skilled labor and technicians sufficiently met the needs of rural sanitation in lesser than 20% of countries participating in the survey (WHO 2014).

Developments in the efficiency of water use could be instrumental in addressing the estimated gap of 40% between demand and supply of water, thereby providing a strong strategy for mitigating water scarcity by 2030 (UNEP 2011). Inadequate or inappropriate collection, treatment, and disposal and reuse of municipal and industrial wastewater is not just a serious health concern, but also a threat to aquatic ecosystems. Efficiency is therefore essential in every stage of water usage as well as wastewater management.

Industry

Industry consumes around 10% of the water it actually withdraws. The rest is converted to wastewater that is laden with enormous loads of pollutants. Wastewater management therefore has a crucial role to play in industries. Adequate water is not only a challenge operationally and a cost-bearing material for industries, but also a growth opportunity in the form of incentives for abated water use. This is generally achieved by recycling and reuse. These are the factors that promote cost savings and decrease water dependency for industrial units.

The power industry is a huge consumer of water as large volumes of water is needed to run turbines (hydroelectric plants) and as coolants (thermal and nuclear power generation). The water used can however be almost completely recycled with meager loses. Moreover, alternate coolants or cooling technologies, such as dry cooling towers, can be used instead of water in the process which draws huge quantity of water. Water-intensive industries such as textile and dying industries should also be promoted to use alternate technologies such as waterless dying. See ► Chap. 41, "Nanomembranes for Environment"

Regulations pertaining to effluent discharge as well as effluent quality need to be implemented strictly. Penalties and fines should be imposed if the norms were not met with. Regular monitoring and inspections as well as data generation pertaining to quantity and quality of such flows should be maintained by the pollution control and regulatory bodies of the respective city, state, or country.

Agriculture

Technology has a key role to play in conserving water within the agricultural sector. Efficient techniques of irrigation can lead to substantial reduction in water loses. Water consumption ranges from 30% to 40% for flood irrigation to 90% for drip irrigation (Cosgrove and Rijsberman 2000). The remaining fraction of water in each case is usually reusable. However, the quality of water is deteriorated owing to dissolution of high amounts of salts, nutrients, pesticides, and other agrochemicals. It is therefore pertinent to use the most efficient technology available in agriculture as this sector is the largest producer of wastewater.

Another important means of conserving water is the use of treated or untreated wastewater in agriculture. However, there is no comprehensive inventory with regard to the extent of treated or untreated wastewater used in agriculture. The total area irrigated with raw and diluted wastewater have been estimated to be around 5–20 million hectares, with China holding the largest area (Drechsel and Evans 2010). This accounts to 2–7% of the world's total irrigated area. It was also estimated that the area of agricultural land treated with unsafe water scales to ten times larger than that irrigated with adequately treated wastewater.

While in Jordan, planned use of wastewater for irrigation being practiced since 1977 enables the use of 90% of the treated wastewater in irrigation (MWI 2016), treated wastewater in Israel constitutes 40% of the total volume of water used for irrigation (Mountford 2011).

The selection of crops to be grown in a specific hydrogeological condition should also be carefully decided. Regions where groundwater is overextracted should be monitored not to allow crops that are water intensive, especially cash crops. Good farming practices such as crop rotation and mixed farming, farm tilling, etc., should be promoted not only to conserve water but also to reduce the application of harmful agrochemicals in crop fields.

Acceptability Towards Reuse of Water

Lack of awareness and trust can result in strong opposition from the civic community towards the reuse of treated or untreated water/wastewater. Cultural and religious beliefs too can have a key role in building perceptions. Winning the confidence of the common mass by indulging them in all the processes concerned with the treatment and reuse of wastewater as well as effective demonstration are essential steps in order to eliminate these kinds of hindrances. This is important as cultural mind-set and consumer behavior have become central to such reactions rather than health concerns.

Legislation at times provides the thrust required to break the barriers. A classic example is the adoption of legislation permitting the use of treated wastewater by 11 out of the 22 Arab states. This was facilitated by the respective ministries to the states concerned with the use and disposal of wastewater, namely the ministries of environment in Kuwait, Lebanon, and Oman; health ministry of Iraq; agricultural in Tunisia; Housing in Egypt; and standard regulatory institutions in Jordan and Yemen (WHO 2006).

Regulated Abstraction of Water

Unregulated access to groundwater resources, affordable small electric and diesel pumps, and highly subsidized electricity and diesel oil, especially among the rural populations, have led to easy and extensive pumping of groundwater, especially for irrigation and to rapidly falling groundwater tables in several aquifers (Cosgrove and Rijsberman 2000).

Water Subsidy

Several governments have subsidized considerably the services in the water sector, such as, water for irrigation. Some have also provided subsidy on domestic and industrial water supply. This has certainly let the sectors flourish, but the most inexpensive commodity "water" has lost its importance in the attempt. Moreover, the benefits do not reach the intended beneficiary but is rather exploited by the privileged and powerful class of society. A thoughtful and innovative mechanism is needed to assure the goals are rightfully achieved.

Modern Technology

Technologies such as rainwater harvesting, green roofs, and other green infrastructure have enough potential to reduce dependability on water as a resource. These technologies are gaining impetus and have attracted urban populations. These also help in reducing the risk of floods and consumption of energy.

High-income countries like Singapore compensates their water scarcity by investing huge amounts in alternate technologies, such as, desalination of salt water, import of food at the cost of water-intensive agriculture, wastewater treatment, etc.

Conserving Biodiversity

Terrestrial, freshwater, and marine ecosystems are vital to the water cycle. Poorly managed water resources lead to loss of biodiversity within these ecosystems. Diversity and water area are deeply associated with each other. An integrated water management also takes into account the conservation of all the ecosystems as well as their biodiversity. It has been estimated that around 20–35% of freshwater fishes are vulnerable or endangered, due to several factors, such as, habitat alteration, pollution, invasive species, and overharvesting (Cosgrove and Rijsberman 2000).

Water quality seems to be emerging as a massive problem in aquatic ecosystems. Trace chemicals, such as, pesticides, herbicides, pharmaceuticals, etc., which are known carcinogens and endocrine disrupters cannot be removed by conventional methods of water treatment and are posing serious threat to flora and fauna within key ecosystems. Water management should be integrated with environmental management and be committed to conserve biodiversity within ecosystems.

Climate Change

According to the projection made by the Intergovernmental Panel on Climate Change, nearly 7% of the global population will suffer from a decline in renewable water resources by at least 20% as against each degree of global warming (Döll et al. 2014; Schewe et al. 2014).

Climate change augments the complexity of managing water resources (World Bank 2010). Certainly, the impacts of climate change on hydrological variability are associated with the factor of uncertainty. However, in view of the intensity of the unseen crisis, preparedness is crucial. Strategies must be designed in order to flexibly suit the changes expected and aimed at causing no further deterioration in climate change.

Institutional Integrity

In several countries, water is managed by a number of bodies, departments or institutions, each allocated with a defined set of targets. Some are concerned only with groundwater, some with surface water, some with rainwater, and that too with a few aspects of any. This leaves management of the water sector fragmented. There is no scope for the amalgamation of dimensions, disciplines, and stakes. Integrity is therefore the most essential component in order to look for a solution that is sustainable. Institutions therefore have to stand integrated in managing the vast and complicated sector of water management.

Multidimensional Approach

Water is a subject so extensively associated with several disciplines that it can be an exclusive discipline in itself. There can be numerous perspectives associated with water. It covers subjects such as hydrology, sociology, philosophy, history, law, ethics, management, conservation, and so on. To include all the disciplines, science, social sciences, economics, etc., all need to be brought together in order to understand water in totality.

Community Participation: All Inclusive

Surplus technological know-how, modern designs, and effective alternatives have been tried and tested in various sectors to ensure better management of water resources. However, such arrangements have by and large failed to serve the purpose they had been introduced for. Lessons that it gave was to include the participation of the common mass which was left out despite being the ultimate beneficiary of end users. Taking the public into confidence before introducing a technology or an arrangement holds utmost importance in its success.

Yet participatory approaches are not new. Not just the determination of success or failure but numerous benefits have been obtained from such participations. Their indigenous knowledge, experiences, and perspectives hold immense importance in resolving an issue which effects them. Moreover, their expectations and needs are understood better.

Participatory approach, however, is not as simple as it seems. A typical society lays divided based on caste, creed, economic status, power, and influence. Decision making and participation is mainly restricted to the privileged section. This divide must be broken in order to assure a fair participation inclusive of all from each category. Inclusion should be introduced in all stages of development, planning, decision making, execution, implementation, etc. This brings the true sense of ownership among the masses and leads to a successful and integrated management practice.

Job Opportunities

Eight of the water and natural resource-dependent industries, namely, agriculture, forestry, fisheries, energy, resource-intensive manufacturing, recycling, building, and transport, have provided employment to around half of the world's workforce. Forestry and agriculture which are the most sectors threatened because of water disruptions along with fisheries have collectively provided jobs to more than a billion (ILO 2013).

Seventy-eight percent of the jobs constituting the global workforce are water-dependent. It has been estimated that 95% of jobs in the agriculture sector, 30% in the industry sector, and 10% in the services sector depend heavily on water resources. This comprises of 1.35 billion jobs which are likely to be heavily water-dependent (WWAP 2016).

With the increasing trend in shifting towards renewable energy, new job markets have emerged, such as, in solar, wind, and geothermal energy. Although these jobs are not directly based on water, they have emerged greatly in view of the rising world water insecurity. The US Department of Commerce's Bureau of Economic Analysis has revealed that each of the jobs created in the local water and wastewater industry creates approximately 3.68 indirect jobs in the national economy (United States Conference of Mayors 2008).

Training and Capacity Building

The EMM approach of wastewater management largely lacks capacity. Specifically designed training manuals and innovative learning need to be introduced so as to render the staff competent and strengthen institutions, such as governments, their agencies, boards, organizations, both public and private (WWAP 2016).

Conclusion

In accordance with the above mentioned multiple dimensions of an EMM approach towards the management of wastewater, it is well established that this approach aims at conservation of resources along with fostering long-term sustainability. This should be achieved through multiple means such as by improving already existing information about material flow and environmental impacts generated throughout the life cycle. The productivity as well as efficiency of resources too need to be ensured while promoting reuse, recycle, and recovery. It also advances up-gradation of technology for better output in terms of high productivity and low impacts, such as reduction or elimination of wastes and toxins in order to render the process sustainable. Selection, design, and management of materials and processes that are safe and sustainable are equally essential. Laced with the tools of legislation, regulation and policies, it also focuses in providing new and/or improved employment opportunities across all the sections of society. Participation and cooperation between all the stakeholders such as governing bodies, institutions, various organizations, communities at several levels of governance, geographical regions, and the world are also indispensable in achieving the goals of EMM. The amalgamation and integration of disciplines, sectors, and institutions closely associated with wastewater is must. Such integrated and well-coordinated approaches are therefore expected to promote development of networks, strengthening partnerships, capacity building and training to generate skill, and empowerment of communities with the help of appropriately designed participatory approaches.

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