Wastewater treatment and reuse – The future source of water supply

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Abstract

Freshwater supply is critical for the survival of humankind. With the rapid growth of population and urbanization we are confronted with serious water scarcity. Wastewater treatment, recycle and reuse have now become important alternate sources of water supply. Wastewater is used water from domestic, commercial, industrial and agricultural activities. This water if untreated may be harmful to both the man-made and the natural environment. Treating wastewater requires a comprehensive planning, design, construction and management of treatment facilities to ensure that the treated water is safe for human consumption and for discharge to the environment. The potential treatments include primary, secondary and tertiary treatment using mechanical, chemical and biological processes. Nowadays wastewater treatment plays an important role in providing safe water to ease water scarcity in some areas.

Keywords

Wastewater treatment, Primary treatment, Secondary treatment, Tertiary treatment, Chemical treatment, Biological treatment, Mechanical treatment, Water scarcity, Wastewater recycling

1.0 Introduction

Freshwater supply is essential to sustain economic activities and the well-being of humankind. Nowadays water quality and scarcity have become prior concerns in most countries, in particular developing countries. Of the total available water on earth, approximately 97% is salty, that is, not suitable for human consumption. Of the 3% of freshwater, only one third is of drinking water quality that can sustain human's daily lives and other usage (Ranade & Bhandari 2014; Djukic etal. 2016).

More than 98% of the earth's freshwater is either locked in ice over Antarctica and Greenland or occurs as ground water, whilst approximately 2% is available in streams, rivers and lakes. Water is an important renewable resource that sustains human life and economic activities. However contamination of ground and surface water has become a serious concern at national and international levels. Tiwari et al. (2008) state that ground water as being the main water source has been extracted far quicker than its rate of regeneration. This is due to an increasing water demand for irrigation, urban consumption and industrial processes as a result of rapid population growth and urbanisation.

Population growth and urbanization are main reasons for water scarcity (Bixio etal. 2008; UNESCO 2015; Gupta et al. 2012; Ranade & Bhandari 2014). According to Ranade and Bhandari (2014), since 1950 the world population has doubled while water consumption has increased six fold. Global population growth has caused an unprecedented increase in the demand for freshwater. As stated in a world water report published by the United Nations, by 2025 two-thirds of the population in the world could face serious water scarcity, particularly in developing countries such as China, India and in Africa (UNESCO 2016). Economic growth, industrial development and urbanization have generated ever-increasing demands for freshwater. Lu etal. (2010) state that among the 640 major cities in China, more than 300 face water shortages and about 100 face severe scarcities.

The problem of water scarcity is not just caused by the increasing demand for freshwater but is also due to wasteful practices and inappropriate water management. Human related factors and also wastewater generate high levels of biochemical oxygen demand (BOD) that further aggravates water scarcity. Water pollution as a result of human and economic activities has compromised the capability of ecosystems and the potential of the natural water cycle to satisfy the world's growing demand for water (UNESCO 2015). The contamination of water sources due to the discharge of untreated wastewater adds to the problem. Ranade and Bhandari (2014) argue that a significant proportion of wastewater in developing countries is discharged untreated, resulting in the contamination of ground water, rivers and other water sources. According to the water report published by the United Nations, high water quality risks due to excessive BOD will affect 20% of the global population by 2050 (UNESCO 2016).

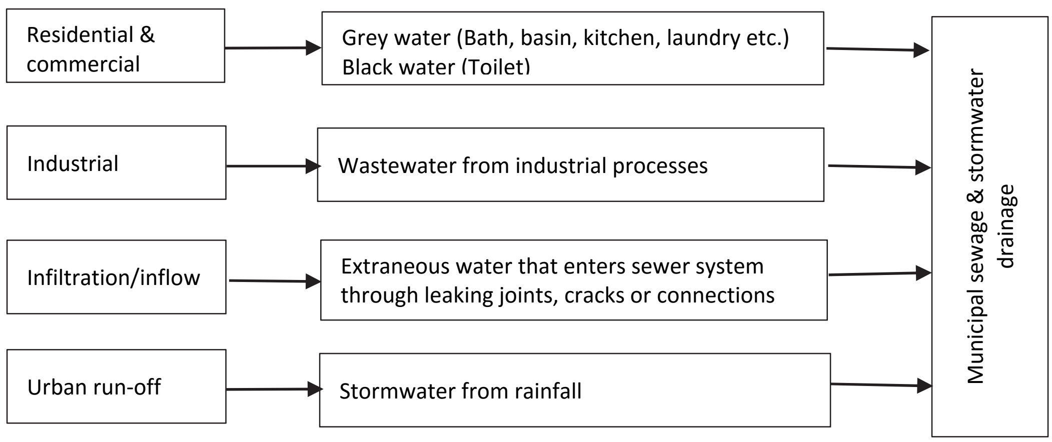
This article reviews problems and sources of water contamination. The chapter also reviews various wastewater treatment and recycling technologies in primary, secondary and tertiary treatment. The chapter discusses the wastewater management systems that combine various treatments and recycling technologies on a larger scale to reduce our water footprint and includes case studies to demonstrate the concepts covered. The chapter ends with a discussion of the challenges of and barriers to wastewater recycling and reuse.

2.0 Water contamination

Water is regarded as contaminated when pollutants such as lead, nitrates and pesticides are present. Water sources can be contaminated by point or non-point sources that mainly come from industrial, domestic, agricultural, and other environmental and global changes. Water pollution due to the accumulation of wastewater discharged without treatment is the most comprehensive global environmental issue that affects the health and safety of humankind (Djukic et al. 2016).

Sonune and Ghate (2004) define wastewater as a combination of liquid or water carried waste removed from human activities. The types of pollutants in wastewater depend on the nature of industrial, agricultural and municipal wastewater releasing activities. Figure 1 shows the origin and flows of wastewater in an urban environment. The wastewater is generated from various sources but all discharged to the municipal wastewater collection system.

Figure 1 - Origin of wastewater in an urban environment



Source: Veenstra et al. 1997; Sonune & Ghate 2004

Wastewater from municipal sewage and stormwater drainage is mainly generated from domestic, commercial, and industrial sources and can be either grey or black water, treated or untreated. Industrial wastewater is water used during industrial processes such as cooling, processing, cleaning, transporting, and flushing. The concentration and composition of wastewater from the industrial sector can vary a great deal and is more complicated to treat than is domestic wastewater. Increased industrial development has produced many pollutants such as endocrine disruptors, explosives and heavy metals to surface and ground water (Naik & Stenstrom 2012).

The type of pollutants in wastewater will depends on the nature of activities. Wastewater usually contains a high load of oxygen demanding wastes, pathogenic or disease-causing agents, organic materials, nutrients, inorganic chemicals, minerals and sediments (Gupta et al. 2012). Many of these pollutants may be toxic and carcinogenic in nature. Pollutants in wastewater can be largely categorized into organic and inorganic matter (Gupta et al. 2012). Organic matter can be toxic and originates in pesticides which include insecticides, herbicides, fungicides in addition to polynuclear hydrocarbons, detergents, oils, greases, etc. The most common inorganic water pollutants are heavy metals, nitrates, sulphates, phosphates, fluorides, chlorides and oxalates.

The contaminants in wastewater may have negative impacts on the aqueous environment if they are discharged untreated. The presence of some pollutants such as oil, heavy metals, ammonia, sulphide and toxic constituents may damage sewers via corrosion and reduce treatment plant performance.

The use of chemicals in agriculture such as nitrogen and phosphorus increase the nutrient content in water which causes eutrophication. Eutrophication is a process caused by the enhancement of the surface water with nutrients that may cause accelerated growth of algae and other aqueous plants. This will create an imbalance among the organisms in the water and impair the quality of the water (Veenstra et al. 1997; Djukic et al. 2016). The different types of micro-organisms, such as bacteria, fungi, algae, plankton, amoeba, viruses and worms, thriving in wastewater are often responsible for different types of diseases (Gupta et al. 2012).

3.0 Wastewater treatment technologies

Wastewater treatment is a process that involves protecting human health by removing wastewater away from populated areas and transforming it into a harmless form. Properly treated wastewater can then be discharged back to the aqueous environment contributing to the global natural water reserve or recycled for domestic and industrial use to ease the demand for freshwater. Wastewater treatment is regarded as an effective way of reducing human water footprint. However the effectiveness of wastewater recycling and reuse will depend significantly on the technologies and how reliable and effective they are in converting wastewater into safe usable water.

Basically, wastewater treatment addresses the problem of water availability by ensuring that wastewater does not contaminate water sources and by recycling treated water to add to the supply of safe water (Gupta, Ali, Saleh, Nayak & Agarwal 2012). For a typical wastewater treatment system facilities are required to undertake three levels of treatment processes namely primary, secondary and tertiary (Sonune & Ghate 2004; Gupta, Ali, Saleh, Nayak & Agarwal 2012; Ranade & Bhandari 2012). The use of these processes will depend on the level of contamination, nature of pollutants, and the intended use after treatment. Table 1 summarizes the three levels of wastewater treatment processes.

Table 1 - Summary of wastewater treatment technologies

Treatment	Purposes	Processes	Outcomes
Primary (Mechanical)	• Preliminary purification process to remove gross, suspended and floating substances	• Screening to trap solid substances • Sedimentation by gravity to remove suspended solids	• Reduce BOD by 20-30% • Reduce total suspended solid substances by 50-60%
Secondary (Biological)	• Involves oxidation of dissolved organic matter by means of biological active sludge and pollutants then being filtered off • Remove dissolved organic matters that escape the primary treatment	• Using microbes digesting the organic substance as food, and transforming it to carbon dioxide, water and energy for their own growth and reproduction • Water is circulated in a reactor that maintains a high concentration of microbes • Then followed by additional settling tanks	• Remove about 85% of the suspended solid substances and BOD by a well running plant

Tertiary	• Additional process to convert wastewater into good quality water to suit different purposes of use	• Advanced chemical or biological methods of removing nitrogen and phosphorus • The related technology can be very expensive, highly technical and energy intensive	• Can remove 99% of all impurities • Producing an effluent of drinking water quality
Sources: Sonune & Ghate 2004; Gupta et al. 2012; Ranade & Bhandari 2012 www.water.worldbank.org/show-resource-guide/infrastructure/menu-technical-options/wastewater-treatment			

3.1 Primary treatment technologies

Primary treatment is the first stage of wastewater treatment. The first stage of wastewater treatment may begin with a preliminary screening process to remove large pieces of trash such as rags, wood, paper, bottles, cloth and similar items. The main objective of this treatment is the removal, through sedimentation, of large and coarse organic or inorganic solids in order to protect plant equipment such as sewage pumps, pipes in the downstream treatment process. Therefore this treatment is to produce water quality suitable for treatment in the secondary and tertiary stages to avoid blockage and process failure. The screened garbage is disposed to landfills.

Following the preliminary screening process the wastewater is delivered to settling tanks where heavier solids are settled to the bottom whilst lighter materials are allowed to float to the surface of the tank. The floatable materials such as oil, small plastic are removed from the surface of the tanks. The settled solid, called primary sludge, are pumped through cyclone devices to separate sand, grit and gravel from the sludge using centrifugal force. The separated sludge is then disposed to landfill. The remaining solution from the primary settling tanks then flows to other tanks for the secondary treatment system to take place.

The water quality after treatment from this process is not suitable for discharge, recycling or reuse. For wastewater to be suitable for recycling or reuse secondary or tertiary treatment is necessary in order to remove other pollutants and improve the water quality. Even though this treatment is largely mechanical, chemicals are often used to accelerate the sedimentation process. Table 2 summarizes the technologies commonly used at this stage of wastewater treatment.

Table 2 - Summary of technologies used at the primary treatment of wastewater

Technology	Process
Screening	• This is the very first step aiming at removing large and floating non-biodegradable solids and waste e.g. cloth, paper, wood, cork, hair, fibre, faecal solid, etc. using screens. • The screens consist of installing inclined parallel bars, wires or grating placed across the wastewater flow. • The screens can be manually or mechanically cleaned. • The process is an initial screening to avoid damage or blockage to the operation and maintenance of further treatments in the downstream plant, equipment and pipelines. • Three types screens are available and they are coarse (pore size ≥ 50 mm), medium (pore size 25-50mm) and fine screen (pore size 10-25mm).

Filtration	• Wastewater is passed through fine physical barriers having fine pore size of about 0.1-0.5 µm to remove solids, viruses, bacteria and other unwanted molecules. • Different types of membranes are used for softening, disinfection, organic removal, and desalination of wastewater. • There are four processes currently used namely ultrafiltration (UF), reverse osmosis (RO), nanofiltration (NF) and microfiltration (MF). • With the advancement of technology the cost of filtration has reduced significantly in operating in small buildings and land sizes. • Can remove solid size below 100 mg1^{-1}, oil size of 25 mg1^{-1}
Centrifugal separation	• Remove suspended non-colloidal solids of size up to 1 µm from wastewater • Use the action of centrifugal and gravity resulting from high rotation speed to separate components of different densities with larger and denser particles sedimenting faster.
Sedimentation	• Separate suspended particles from water by gravity in an either undisturbed or semi-disturbed state for different time intervals in various types of tanks • Used for grit removal, biological floc-removal in activated sludge settling basin and solid concentration in sludge thickeners • Effective to remove pollutants such as microbial contaminants, toxic metals, synthetic organic chemicals, etc. • Can remove suspended solids by up to 60%
Coagulation	• One of the most commonly used methods • Coagulant e.g. synthetic cationic, anionic, non-ionic polymers are used to destabilize colloidal particles in wastewater • Typically applied prior to sedimentation and filtration to enhance the ability of a treatment process to remove particles • However this process may result in large volumes of sludge to be disposed
Floatation	• Remove suspended solids, oils, greases, biological solids, etc. by adhering them with either air or gas so that they form into agglomerates which can be removed • Effective in wastewater high in fat, oil and grease content • Remove up to 75% of suspended solids and up to 99% of oil and grease
Sources: Veenstra, Alaerts & Bijlsma 1997; Sonune & Ghate 2004; Gupta, Ali, Saleh, Nayak & Agarwal 2012; Ranade & Bhandari 2014	

3.2 Secondary treatment technologies

The partially treated wastewater will be treated further using technologies from the secondary treatment process. Secondary treatment is largely biological treatment of wastewater. This secondary treatment is called a biological process aiming at removing organic and non-organic matters. This treatment removes soluble and insoluble organic matters using microbes. The main goal of the process is to remove biochemical oxygen demand (BOD) by removing dissolved and finely suspended biodegradable organic matter from wastewater in a controlled environment where microbes are the main removal agents. Microbes are usually bacterial and fungal strains that convert organic matter into water, CO_2 and ammonia gas or other by-products such as alcohol, glucose, nitrate, etc. Additionally, the microbes may detoxify toxic inorganic matter.

In the treatment process air is added to the wastewater in aeration tanks that simulates the growth of oxygen-using bacteria and other organisms that are naturally present in the sewage. These microorganisms will breakdown organic matters that are polluting the water. The digestive process produces heavier substances that will settle at the bottom of the tanks later in the treatment process. The aerated wastewater then flows to the final settling tanks and heavy particles settle to the bottom forming secondary sludge is to be removed and disposed. There are a variety of technologies can be used in the process and Table 3 summarizes the technologies that are commonly used for secondary treatment of wastewater.

Table 3 - Summary of technologies used at secondary treatment of wastewater

Technology	Process
Aerobic	• This is a process using bacteria causing biodegradable organic matters to undergo aerobic decomposition in the presence of oxygen • Effective in removing BOD and COD, dissolved and suspended organics, volatile organics, nitrates, and phosphates using microbes • A suitable treatment for low strength wastewater • Two commonly used systems are activated sludge systems and aerated stabilization basins • Can reduce up to 90% of the concentration of biodegradable organics • Oxidation degradation of the carbon substrates provides the energy required for propagation of the micro-organization that act as the biocatalyst • The process may results in the production of large quantity of biosolids which may require further costly treatment
Anaerobic	• This process is used when dissolved oxygen is not available. • The process involves using anaerobic and facultative bacteria to convert the complex organ matters into simple organic compounds • This is an energy efficient process that is usually used to wastewater that is warm and contain high concentration of biodegradable organic matters • This process uses less energy, requires less chemical and incurs lower sludge handling costs compared to aerobic treatment option • The process produces biogas in the form of methane (CH_4) and CO_2 which can be stored and used for energy production • The two main systems are batch systems where biomass is added into a reactor to undertake the digestion process and continuous systems will require a constant feed of organic matter to the treatment system. • Effective in removing heavy metal • Nearly 95% organic contamination is converted into combustible gas
Sources: Sonune & Ghate 2004; Gupta et al. 2012; Ranade & Bhandari 2014	

3.3 Tertiary treatment technologies

Tertiary treatment, also known as advanced treatment, is a very important process as this process will ensure the safety quality of drinking water for human consumption. Therefore a final treatment process, tertiary treatment, may still be required to ensure water safe for drinking purposes. The technologies in tertiary treatment are used to further improve the water quality and the types of technologies to be used will depend on the expected use. Typically, disease-causing organisms can be removed by using chlorine mixed with sodium hypochlorite. The disinfected water can then be released safely into local waterways. The related technology can be very expensive and energy intensive that require fully equipped plants and highly trained staff to operate during the entire process. The technologies that are commonly used for the tertiary treatment of wastewater are summarised in Table 4 below.

Table 4 -Summary of technologies used at the tertiary treatment of wastewater

Technology	Process
Distillation	• Wastewater is heated up to 100 °C and the vaporized water will leave pollutants behind • The boiling process also kills biological contaminants • Cooling process will be applied to turn vapour into clean water for recycling and reuse • Commonly used methods are solar distillation where solar energy is used in the process and multistage flash distillation operates in lower pressure to heat water into steam in a number of stages • Effective in removing soluble minerals and heavy metals • Treated water is about 99% free from impurities
Crystallization	• This is a process of turning pollutants into crystals by increasing their concentration point • It can be done by either evaporation, reducing the temperature of wastewater or by mixing with other solvents • This method is useful for wastewater treatment with high concentration of TDS
Evaporation	• This is a process of changing a liquid substance to a gas or a vapour when heat is applied at the boiling point • Evaporators convert the water component in the wastewater to clear vapour that condenses into clean water • Effective for removing salts, heavy metals and a variety of hazardous materials in wastewater
Solvent extraction	• Extractants are added to wastewater to remove pollutants • Organic solvents such as benzene, hexane, acetone and other hydrocarbons are commonly used extractants • This method is effective in eliminating organics, oils and greases
Oxidation	• Oxidants are used to trigger chemical oxidation so that organic compounds are oxidized into water, CO_2 and other by-products e.g. alcohols, aldehydes, ketones , carboxylic acids • The rate of oxidation will depend on the nature of oxidants and pollutant, pH, temperature and presence of catalyst • This method is effective in eliminating pollutants e.g. ammonia, phenols, dyes, hydrocarbons and other organic pollutants
Advanced oxidation process (AOPs)	• Similar to oxidation but AOPs may involve simultaneously more than one oxidation process • This method involves the augmented production of the highly reactive hydroxyl free radical • This methods is capable of reducing organic pollutants at ambient temperature and pressure
Precipitation	• A precipitation substance is added so that dissolved contaminants are converted into solid particles • Filtration then can be used to remove the particles from the mixture

	• Effective for metal ions and organics but may cause a problem with the presence of oil and grease
Ion exchange	• Non-toxic ion exchangers are used to exchange with toxic ions in wastewater as water passing through granular chemicals • Most commonly used ion exchangers are sodium silicates, zeolites, polystyrene sulfonic acid, acrylic, metha-acrylic resins • Effective for removing low concentration of organic and inorganic by up to 95%
Reverse osmosis	• Wastewater is pumped at a pressure greater than the osmotic pressure through permeable membranes to drive water away from dissolved molecules. • The membrane used has the smallest pores and can remove up to 99% of pollutants. • This method is commonly used for industrial process either to treat wastewater or to reduce the amount of wastewater for disposal. • The commonly used membranes can be in cellulose, polyether, polyamide in tubular, disc, plate, spiral and hollow fibre forms
Nanofiltration	• Similar to RO but targeting in the removal of divalent and larger ions. • Commonly used for hardness removal, pesticide elimination and colour reduction.
Micro- and ultra-filtration	• This is a pressure-driven process that eliminates emulsified oils, metal hydroxides, colloids, emulsions, dispersed material, suspended solid, and other large molecular weight materials from wastewater. • To remove particles of 0.04 to 1 µm in size • Filters used are made of cotton, wool, rayon, cellulose, fiberglass, polypropylene, acrylics, nylon, asbestos and fluorated hydrocarbon polymers in the form of tubular, disc, plates, spiral and hollow fibre forms • Pre-removal of suspended solids is important
Adsorption	• Solid adsorbents are used to remove pollutants • Activated carbons, fly ashes, metal oxides, zeolites, moss, biomass, geolithes are commonly used adsorbent. • The presence of suspended objects and oils may reduce efficiency. Therefore pre-filtration is a necessary and important process • Recent development in the use of nanomaterials includes carbon nanotubes and composites of carbon nanotubes to remove heavy metal and organic pollutants
Electrolysis	• This is an electro-chemical redox reaction to enable soluble materials either deposited or decomposed on the surface of the electrodes by passing electricity through water to be treated • Most metal ions are deposited on the electrode surface while organics are decomposed into CO_2 and water or other low or non-toxic by-products • Effective in removing turbidity and colour for wastewater
Electrodialysis	• Electric current is introduced to wastewater so that water soluble ions can pass through ion selective semi-permeable membranes which are normally made out of ion exchange material • These membranes may be cation or anion exchangers which permits the outflow of cation or anion respectively
Cavitation	• Certain organic pollutants e.g. dye, pigment, textile are considered refractory compounds that are difficult to remove or degrade by using

	conventional methods. Therefore cavitation is used to pollutants or complex organic molecules using hydrodynamic, acoustic, optic and particle cavitation to destruct organics
Incineration	• Toxic organic materials e.g. pesticides, herbicides and chlorinated hydrocarbons are difficult to remove by conventional processes as these pollutants are most difficult to degrade biologically or can't be economically removed by any of the physico-chemical methods of separation • Extreme high temperature (980-1500 ^{o}C is used to allow organics to oxidize along with some of the inorganic in the presence of oxygen • Coupled with high temperature waste treatments are recognized as thermal treatment
Sources: Gupta et al. 2012; Kislik 2012	

3.4 Selection of technologies

Wastewater treatment is usually aimed at protecting public health, preserving oxygen content in water, preventing eutrophication, sedimentation and toxic compounds from entering the water cycle and food chains. The selection of appropriate technologies will depend on the characteristics and types of pollutants present in the water and intended use of the treated water. The treated water is governed by standards or guidelines to the water quality classes as set by governments according to the expected quality or use of the treated water. Therefore appropriate treatment technologies are to be used to remove or prevent the discharge of the contaminants concern back to the environment.

Generally, highly polluted wastewaters with solid pollutants are required to be firstly treated with primary treatment followed by secondary treatment. However if BOD is negligible then a secondary treatment may be deemed not necessary. According to Gupta et al. (2012) if wastewater is colourless and contains no solid pollutants then only tertiary treatment is deem to be necessary. However if groundwater is polluted by toxic metal ions and anions, neither primary nor secondary treatments are required and only tertiary water treatment is required. For contamination of surface water both secondary and tertiary treatments are required to treat the water.

The performance and reliability of a specific technology is another important consideration. Some technologies may have the capacity of removing pollutants other than just the targeted pollutants. The technology used for wastewater treatment should be stable to both operation process and reliable to produce an acceptable wastewater under any unusual conditions. Financial consideration is another aspect as the lower the financial costs, the more attractive is the technology.

4.0 Wastewater treatment systems

4.1 Combined wastewater treatment processes

These systems are used to convert wastewater into treated water before discharging back to the environment. Holiday (2008) states that wastewater treatment systems can be intensive and extensive systems. Intensive systems involve a small footprint at a cost of engineering complication. These systems use chemicals to achieve oxidation, precipitation or nutrient removal. Some systems combine biological and chemical processes in the treatment. Commonly used intensive wastewater treatment systems are activated sludge, membrane bioreactors, sequencing batch reactors and package plants. Extensive systems, on the other hand, are more land intensive but robust with low energy consumption.

According to Muga and Mihelcic (2008) wastewater treatment technologies can be broadly divided into mechanical, lagoon and land treatment systems. Mechanical systems aim at removing nutrients, pathogens, metals and other toxic compounds using physical, chemical and biological mechanisms. Economically these systems require the highest capital, operation and management costs. Lagoon systems use predominantly physical and biological processes to treat wastewater. These systems do not require high capital, operation and management costs. The energy use is relatively low compared with mechanical systems and low risk of odour. Additionally these systems provide open space for local community as well as contributing to economic growth by providing employment opportunities for the operation of these systems. Land treatment systems utilize soil and plants to treat wastewater without significant need for reactors and operational labour, energy and chemical. The cost of capital, operation and management is relatively low.

4.2 Wastewater treatment projects

There are a number of published case studies of different aspects of the treatment of wastewater. Cazurra (2008) undertook a case study of wastewater reuse in the South of Barcelona, Spain. A wastewater reclamation plant was built in South of Barcelona to help address the water scarcity problem locally. The project was designed to release 50Mm^3/year of recycled wastewater to improve the ecological flow in the lower part of the Llobregat River and to supply water for irrigation of farming and wetlands in the river delta. The wastewater treatment process includes a pre-treatment to eliminate solid substances such as sand and grease. The water then passes through a secondary activated sludge biological treatment process with nutrient removal before undertaking a tertiary treatment. The process includes anaerobic, anoxic and aerobic zones in order to reduce nitrogen and phosphorus concentration in the water. At the tertiary treatment stage the wastewater passes through a regulation basin to regulate flow from the secondary treatment. At this stage treatment include coagulation flocculation, filtration (10 µm pores), ultraviolet radiation for disinfection, additional disinfection and oxygen saturation.

Crook (2007) presents another case study of the wastewater treatment process for the Cary, North Carolina in the US. The population growth in the 1990s has put a great pressure on increasing demand for freshwater. After a water recycle and reuse feasibility study in 1997 a wastewater treatment and reclamation plant was constructed in 2001. The treatment process begins with a preliminary treatment using screening to remove grit and grease. Secondary treatment includes using activated sludge via oxidation ditches to remove biological nutrients. Filtration is then used with continuous backwash upflow sand filters to further remove impurities. Water is disinfected using ultraviolet radiation, which is then and followed by aeration using a cascade aerator. Sodium hypochlorite is added to water before it enters into a storage tank to provide a target chlorine residual of 0.5 mg/L. The treatment results in quality water for irrigation, manufacturing processes, industrial cooling, street sweeping and dust control at construction site. The goal of the project is to reduce per capita freshwater demand by 20% by 2020.

5.0 Wastewater management - recycling and reuse

5.1 Importance of recycled wastewater

Growing global demand for clean water due to rapid population growth and urbanization make wastewater recycling and reuse an important strategy to increase water supply and reduce water footprint. Treated wastewater can be recycled to cope with the scarcity of water resources and severity of water contamination (Miller 2006). Wastewater recycling considered an important alternate source of water (Miller 2006; Rijsberman 2006; Yi et al. 2011) and represents a valuable long-term solution to the challenges of increasing freshwater demand by the domestic, agricultural and industrial sectors.

Treated wastewater has various reuse values. Recycled wastewater is commonly used for non-potable purposes such as irrigation and industrial uses (Bixio et al. 2008). Recycled wastewater if used for irrigation for agricultural purposes can help to increase groundwater recharge and greatly increased crop yields as recycled water contains nutrients that are beneficial for crop growth, resulting in savings in fertilizer application. However the high salt content in recycled wastewater may impact plant productivity for long term usage. Therefore, removing salt from wastewater during the treatment process is important.

Faced with water shortage and pollution, many cities around the world have utilized recycled wastewater to refill pools, ponds and lakes and water features to replace the demand for potable water from the mains. Commercially and domestically, treated wastewater is used for toilet flushing with reticulation system to supply recycled water (Yi et al. 2011). For the industrial sector recycled wastewater can be used in many different ways such as cooling water, processing, water need for power station, steel production, oil refining and other manufacturing sectors (Bixio et al. 2008; Yi et al. 2011).

Ranade and Bhandari (2014) propose a hierarchical approach as a strategy for wastewater management. The hierarchical approach involves identification and solution at every stage of operation. At the base of the hierarchy, pollution prevention and waste minimization is the most preferred approach where existing processes are modified so that waste generation is avoided. The next level up is wastewater treatment where it is determined whether the treated water can be recycled and reused so that water footprint can be reduced. The third level in the hierarchy is interlinked with wastewater treatment. The last level in the hierarchical pyramid is disposal when wastewater is absolutely untreatable and cannot be recycled in any way to be disposed in a landfill.

Most wastewater is delivered and collected at the municipal level for a more intensive offsite treatment at the centralized treatment plants. The treated water can achieve the required quality to suit the intended reuse purposes of agricultural, industrial and ground water recharging. In addition wastewater can also be partially treated onsite and reused for purposes like landscape irrigation. This applies to wastewater from residential, commercial and industrial bathroom sinks, bath, shower and laundry drains. This is however only possible with the use of non-toxic and low-sodium products in order to protect vegetation. For wastewater treated and reused onsite the National Science Foundation (NSF) International has established a standard NSF/ANSI 350 and 350-1: *Onsite water reuse guideline*s to set quality requirements for the reduction of chemical and micro-biological contaminants for non-potable water use (Bruursema 2011). These guidelines provide recommendations for the material, design, construction and performance required for onsite residential and commercial greywater treatment systems.

In summary, the benefits of wastewater recycling include (Jefferson et al. 1999; Bixio et al. 2008):

- Satisfying increasing freshwater demand
- Replacing the demand for freshwater for industrial usage such as cooling water for power plants and oil refineries
- Reducing wastewater disposal and related facilities
- Reducing the amount of pollutants being discharged to protect water quality in the environment
- Reducing potential risk of human exposure to untreated wastewater

- Typically using less energy than importing freshwater as wastewater is locally treated and recycled
- Lowering the cost of developing new water sources e.g. desalination plants
- Recharging ground water, aquifers and augmenting surface water reservoirs
- Localized wastewater reuse can help saving capital cost of diversion structures, discharge pump stations and pipelines for discharging wastewater

5.2 Wastewater recycling and reuse projects

Wastewater recycling and reuse play an important role in the sustainable management of natural water resources. Successful projects of various scales have been implemented in many countries. Wastewater recycling and reuse have been integrated as part of urban water planning at the municipal level. Integrated urban water planning is a structured planning process aimed at evaluating potential opportunities to improve water source management and implementing a combined system of discharging sewage and stormwater. Integrated urban water planning also undertakes an assessment of water supply and flow conditions to eliminate the sources of nutrients from discharging in the catchment. Since early 1940s wastewater has already been treated and recycled for agricultural irrigation in China (Yi et al. 2011).

Bixio et al. (2008) undertook a research study on reuse of municipal wastewater in Europe. The research identified more than 200 water reuse projects where treated wastewater was reused for agricultural, industrial, urban, recreational and environmental. Lu et al. (2010) in a study of wastewater recycling for the textile industry found that the reuse of wastewaters represents an economic and ecological challenge for dyeing and finishing for the sector. Reclaimed wastewater can conserve and or supplement the available water resource and help to reduce environmental pollution in China.

In 2013 the largest wastewater treatment facility in the world was built in the Central Park development and will be the highest Australian standard for water recycling and reuse (Anonymous 2014). Central Park development was a mixed-use urban renewal project in the CBD of Sydney, Australia. The site was approximately 6,400m^2 and was formerly owned by the Carlton & United Breweries since 1983. This project was one of the largest urban renewal projects in Sydney that includes multi-unit apartments, high-rise commercial and retail offices and parklands (The Capital Group 2012). One of the important and most influential aspects of the project is the world's largest wastewater treatment facility that is capable of harvesting wastewater from kitchen sinks, washing machines, bathrooms, toilets from apartments, shops and offices for reuse (Anonymous 2014). In addition rainwater, stormwater, car park drainage and water from gardens and the green wall (located in One Central Park apartment building) are also harvested across the precinct for recycling and reuse.

All the wastewater collected is sent to the Central Park Water Centre which is a four storeys wastewater treatment facility located at the basement of the building named One Central Park. The Central Park Water Centre has the largest Membrane Bioreator (MBR) facility for wastewater treatment in the world (Anonymous 2014). One Central Park building is a mixed-use building that contains retails at the ground floor with offices and residential above. The wastewater collected at the Central Park Water Centre will undergo eight processes of water treatment that includes filtration, reverse osmosis and ultraviolet treatment (Central Park Plus 2016). The treatment process includes a preliminary screening to remove plastics, rubbish, wood, clothes, etc. After the preliminary screening the wastewater enters biological processing tanks to undergo the anaerobic treatment using microbes to breakdown organic matter into water, CO_2 and ammonia gas. The wastewater is further treated using the aerobic processing in the aeration tanks by adding air to simulate the growth of oxygen-using bacteria. Four chemicals (Sodium Hydroxide, Sodium Hypochlorite, Aluminium Sulphate and

Acetic Acid) are also used at different stages to purify the wastewater. Following the anaerobic and aerobic treatments the purified wastewater is forced through microscopic membranes and the bacteria, pathogens and other impurities will be screened off by the very tiny holes of the membranes. The purified water is then passing through the ultraviolet purification process to remove any remaining impurities. The water quality is further improved by using reverse osmosis which is a membrane filtration technology to further remove small molecules, ions and salts. Finally treatment process is completed by adding chlorine to the water before it is reused for non-portable purposes.

The treated wastewater will then delivered to user via specially coloured taps for cooling towers in air cooling, irrigation for lawns and vertical gardens, toilet flushing, washing machine, car washing. The wastewater recycling and reuse facility at the Central Park development has recycled 1 million litres of wastewater per day and has reduced approximately 40-70% of drinking water which is the drinking water consumption for washing, flushing and cleaning in the community (Central Park Plus 2016).

5.3 Barriers and challenges of recycled wastewater

Wastewater is under-utilized. The potential of wastewater recycling to mitigate water scarcity has not been fully maximized yet. According to Miller (2006) only approximately 7.4% and 9.1% of wastewater was recycled in the US and Australia respectively in 2002. This may be due to the fact that engineers often only compare the financial costs of various alternatives and do not quantify social costs and benefits of wastewater recycling as an option for water supply such as watershed protection, local economic development, employment opportunities and improved public health.

The use of recycled wastewater has also been challenged due to misperception by the general public. Treated wastewater is often assumed to be hazardous to public health due to the potential presence of pollutants such as salts, nutrients (e.g. nitrogen and phosphorus), toxic substances (e.g. ions, organic pollutants) and pathogens. Yi et al. (2011) state that the presence of pollutants in treated wastewater, that can pose potential risks to human health, largely depends on the selection of appropriate technologies for wastewater treatment. Dolnicar and Schafer (2009) undertook a research study on the consumer perception and acceptability of recycled water using a questionnaire survey. The research found that the public generally has very low willingness to adopt recycled water. The research reveals that the public was worried about safety and possible negative environmental, economic and health problems of using recycled wastewater.

Availability of funds for the construction of wastewater treatment and recycling plants and distribution networks is an important challenge (Miller 2006; Yi et al. 2011). Energy consumption and cost play a fundamental role in the decision process for the wastewater treatment technologies to be used. Higher cost in the treatment processes may incur due to more advanced treatments and the distance of treatment plants from urban regions.

6.0 Conclusion

Increasing water demand in sustaining human live and daily activities has already put a significant stress to the current water reserve in the natural environment. The problem has escalated due to human wasteful behaviour, inappropriate water management and contamination of water reserve due to discharge of untreated wastewater. Wastewater treatment has now become an important way out for the problem and also an alternate source of water supply. Over the years, advancement in wastewater treatment technology has greatly improved the water quality for both drinking quality and the removal of harmful pollutants for other activities. Advances in wastewater treatment technology and health studies of indirect potable reuse have led to the prediction that planned indirect potable reuse will soon become more common.

Wastewater recycling and reuse already represents an important water supply in many areas in the world. It should be viewed as one of the several alternative sources of new water. However its potential is largely untapped, due to a number of barriers, including lack of government support and the public's resistance to planned indirect potable reuse. The general public is sceptical about adopting recycled water in any form and sees it as a hazard to both the natural and man-made environment. To fill the gap in the supply of water it is necessary to focus on current education in schools and public information campaigns to change the perception about treated wastewater. There are already successful projects for wastewater recycling and reuse for agricultural purposes, industrial processes and domestic activities such as toilet flushing and gardening. If wastewater recycling and reuse are to be re-introduced to the water supply for human consumption, treatment technologies may need further improvement to reduce the cost and improve the safety and quality of the treated water. In addition, governments will need to provide more incentives and available funds for treatment plants to be constructed and produce more hard data to demonstrate treated water safety. Lastly, it will also be important to educate the general public so that their misperception of treated waste water can be improved.

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