Consilience: The Journal of Sustainable Development
Vol. 15, Iss. 1 (2016), Pp. 1-33

Planning of Wastewater Reuse Programme in Nigeria

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Abstract

Despite the great awareness on the health and environmental implications of poorly disposed wastewater, the continuous pollution of the environment and surface water with wastewaters generated from domestic, institutional, and industrial activities in many Nigerian cities still remains a major concern. As population grows with rising standard of living, more wastewater is generated and disposed to sensitive environments with negative impacts on humans and ecosystems. To promote sustainable and efficient wastewater management, global attention must be drawn toward wastewater reuse for both potable and non-potable uses. This paper presents baseline information on global wastewater reuse that can serve as a valuable guide on the integration of wastewater reuse in Nigeria as a component of National Integrated Water Resources Management, where wastewater reuse will form an important component of water sources in addition to surface and groundwater sources. It will also eliminate the pollution effects of indiscriminate disposal into sensitive ecosystems.

Keywords: Wastewater, treatment, planning, reuse, Nigeria

1. Introduction

Safe disposal of wastewater still remains a serious problem in Nigeria where it has the potential of causing groundwater and surface water contamination and creates environmental pollution. As the country occupies the position of the largest economy in Africa, coupled with the transformation agenda of the Federal Government, it will begin to experience rapid growth in population, urbanization, agriculture, and industrial development. This growth will also result in corresponding increase in wastewater generation in urban areas raising concerns about environmental pollution resulting from the quality of wastewater disposed to sensitive environments.

The effects of untreated or poorly treated wastewater can be detrimental to public health, the environment, and the economy. If implemented under uncontrolled or unregulated circumstances, poorly treated wastewater can be harmful to living beings (if ingested directly or through irrigated crops) and irrigated soil (due to the chemicals and potential bacteria within the effluent) (Adewumi, *et al.*, 2010 (a)). Water contaminated by human, chemical, or industrial wastes can cause a number of diseases through ingestion or physical contact. Water-related diseases include dengue, filariasis, malaria, onchocerciasis, trypanosomiasis, and yellow fever. In Peru, there was a cholera epidemic that resulted in an estimated loss amounting to three times the expenditure on water and sanitation for the entire country over the preceding 10 years; likewise, in Shanghai, China, a major outbreak of hepatitis A was attributed to sewerage contamination (Rose, 1999). The costs of poorly managed domestic wastewater are very high. In India, the 1994 plague epidemic resulted in a loss of tourism revenue estimated at US$ 200 million. Consequently, no other type of intervention has greater impact upon a country’s development and public health than the condition of clean drinking water and the appropriate disposal of human waste (SIDA, 2000). Discharge of untreated wastewater has a tendency to promote the growth of numerous alien aquatic species that exhibit the characteristics of being invasive and threaten to cause ecological and economic harm. It can also lead to the loss of native stream fauna, which would degrade the entire native stream ecosystem. Invasive aquatic species could also cause economic impacts to agricultural users of water, resulting in crop damage, infrastructure damage, or contamination. Introductions of aquaculture and aquarium species into streams occur via flooding, effluents discharged back into streams, intentional introduction, and by overland travel. In addition, diseases and pathogens associated with untreated wastewater could potentially spread through direct or indirect human contact with the receiving streams or rivers.

Untreated wastewater discharged into the environment is increasingly becoming a major source of nutrients, causing eutrophication of surface water bodies. Eutrophication is a growing problem in Nigeria, and, as a result, the ecological integrity of surface waters becomes compromised, fish populations become extinct, toxic cyanobacteria blooms are abundant, and oxygen levels are depleted. Eutrophication is the rapid growth of phytoplankton species and aquatic macrophytes. In extreme cases, this leads to the development of mono-specific blooms of cyanobacteria. Harmful cyanobacterial blooms are typically characterized by heavy biomass accumulations that often consist of a single or a few species, usually members of the genera *Microcystis* and *Anabaena* (Oberholster*et al.,* 2009). It can also lead to the alteration of the ecological integrity of fresh water resources. This may lead to a decline in macroinvertebrate abundance and composition as well as species richness (Beyene*et al.,* 2009). Finally, eutrophication causes the total depletion of oxygen. This is associated with the accumulation and decomposition of dead organic matter which consumes oxygen and generates harmful gases such as methane and hydrogen sulphide (Nyenje *et al.,* 2010). With these problems associated with discharge of untreated wastewater into the environment, wastewater reuse has become an attractive option for pollution abatement when water reuse replaces effluent discharge to sensitive surface waters bodies, furthermore conserving and extending available water supplies. Other benefits of reuse include the decrease in diversion of freshwater from sensitive ecosystems, replenishment of soil nutrients in agriculture due to irrigation, enhancement of groundwater recharge, delay in future expansion of water supply infrastructure, and the creation or sustenance of wetlands (Angelakis and Bontoux, 2001; Joksimovic, 2006).

Wastewater reuse involves the collection and treatment of wastewater so that it may be used for certain applications. Wastewater reuse can form an important component of both wastewater management and water resource management and can offer an environmentally sound option for managing wastewater that dramatically reduces environmental impacts associated with the discharge of wastewater to surface waters. In addition, reuse can provide an alternative water supply for many activities that do not require drinking water quality and, as such, permit the saved drinking water to be used elsewhere. Costly projects for drinking water supply may also be delayed due to the reduced demand for drinking as a result of reuse. Lastly, reuse is attractive in many communities because the cost of producing treated wastewater has been found to be lower than the cost of producing drinking water. These reasons form the major drivers for wastewater reuse in many communities across the world. The most significant restraints to reuse include the potential risks to public health and the potential for reduced sewer or stream flows.

Wastewater reuse has formed an essential component of water demand management (WDM) in many countries including Jordan, Kuwait, Israel, Spain, Australia, Namibia, Germany, United Kingdom, and the United States (Adewumi *et al.,* 2012). With the broad range of effective wastewater treatment technologies that exist and records of successful wastewater reuse implementation in many of these countries, it has become imperative to evaluate the potential of wastewater reuse as a viable alternative in the drive toward overcoming the challenges of environmental pollution and surface-/groundwater contamination in Nigeria.

2. Global Review of Wastewater Reuse

Unregulated wastewater reuse has been in practice for centuries in many parts of the world. The concept of integrated wastewater reuse, however, has received increase attention in recent times due to the degradation of freshwater resources resulting from improper disposal of wastewater and drought and prediction of further droughts from climate change in many arid areas. Furthermore, reuse has gained traction due to increasing competition for freshwater resources, therefore highlighting the need to conserve higher quality water for suitable uses to meet growing industrial, agricultural and domestic needs. Also, there have been growing demands for greener water strategies and water conservation as well as growing recognition of the resource value of wastewater especially in supplementing freshwater for non-potable uses and irrigation and the high costs of supplying sufficient quantities of potable water to arid areas (WHO, 2006; Ilemobade *et al*., 2009).

Wastewater reuse is an important component of both wastewater management and water resource management. It offers an environmentally sound option for managing wastewater that dramatically reduces environmental impacts associated with discharge of wastewater effluent into surface waters. In addition, reuse provides an alternative water supply for many activities that do not require potable quality water and, as such, permits the saved potable water to be used elsewhere. In arid regions where there has traditionally been a scarcity of water, wastewater reuse technology has been successfully implemented via dual reticulation systems. Examples are in Jordan (Al-Jayyousi, 2003; 2004), Israel (Friedler and Hadari, 2006; Brenner *et al*., 2000), Spain (March *et al.,* 2004), Australia (John, 1996; Eric, 1996; Diana *et al*., 1996; Dillion, 2000), and some parts of South Africa (Marilyn, 2006; Adewumi *et al.,* 2010 (a)). In addition, water scarcity experienced globally has led to the embracing of wastewater and other sources of non-potable water in many large urban areas in regions previously considered to have sufficient water sources like China (Junying*et al*., 2004), Japan (Dixon *et al.,* 1999), Canada (Exall, 2004), Germany (Nolde, 1999), the United Kingdom (UKEA, 2000) and the United States (Okun, 1996). Some existing wastewater reuse projects in various countries are summarized in Table 1.

Table 1. Existing wastewater reuse projects in some selected countries (adapted from Metcalf and Eddy, 2004; USEPA, 2004 and AQUAREC, 2006)

Country	**Location**	**Level of treatment**	**Application (s)**
Argentina	Campo Espejo, Mendoza	Secondary treatment	Unrestricted irrigation
Australia	Aurora, Melbourne	Tertiary treatment	Toilet flushing and irrigation
	Mawson lakes, North of Adelaide	Tertiary treatment	Toilet flushing, irrigation, and car washing
	Bolivar and Virginia Project, South Australia	Tertiary treatment	Groundwater recharge for unrestricted irrigation
	South East Queensland	Tertiary Treatment	Unrestricted irrigation
	Hunter Water	Tertiary treatment	Coal washing and power generation
	East irrigation Scheme	Tertiary treatment	Unrestricted irrigation, toilet flushing, and garden irrigation
	McClaren Vale	Tertiary treatment	Irrigation
	Rose Hill	Tertiary treatment	Toilet flushing and garden irrigation
	Georges River Program	Tertiary treatment	Toilet flushing and garden irrigation
	Northern Shoalhaven	Tertiary treatment	Urban irrigation
	Sydney Olympic Park	Tertiary treatment	Irrigation, water fountains, and domestic/residential uses
	City of WaggaWagga	Tertiary treatment	Landscape irrigation
Belgium	Wulpen	Tertiary treatment	Groundwater recharge and saltwater intrusion barrier
	Waregem	Tertiary treatment	Industrial uses
Brazil	Sao Paulo	Tertiary treatment	Irrigation, industrial, and toilet flushing
Chile	Santiago	Secondary treatment	Irrigation
China	Taiyuan	Tertiary treatment	Industrial uses
Cyprus	Cyprus	Tertiary treatment	Irrigation
Egypt	Egypt	Secondary treatment	Irrigation of tree crops
France	Aubergenville	Tertiary treatment	Groundwater recharge

	Clermont Ferrand	Tertiary treatment	Irrigation
	Noirmoutier Island	Tertiary treatment	Irrigation
Greece	Levadia	Tertiary treatment	Irrigation of cotton
	Amfisa	Tertiary treatment	Olive tree irrigation
	Palecastro	Tertiary treatment	Olive tree irrigation
	Chalkida	Tertiary treatment	Landscape and Forestry irrigation
	Karistos	Tertiary treatment	Landscape and Forestry irrigation
	Lerisos	Tertiary treatment	Landscape and Forestry irrigation
	AgiosKonstantnos	Tertiary treatment	Landscape and Forestry irrigation
	Kentarchos	Tertiary treatment	Landscape and forestry irrigation
	Chalkida	Tertiary treatment	Irrigation and industrial uses
India	Hyderabad	Secondary treatment	Irrigation
Israel	Dan Region Scheme	Secondary treatment	Groundwater recharge for irrigation
	Kishon Scheme	Secondary treatment	Irrigation
	Jeezrael valley	Secondary treatment	Irrigation
	Gedera	Secondary treatment	Irrigation
	Getaot Kibbutz	Secondary treatment	Irrigation
	City of Arad	Secondary treatment	Irrigation
Italy	Emilia Romagna	Secondary treatment	Irrigation
	Grammichele	Tertiary treatment	Irrigation
	Palermo and Gela	Tertiary treatment	Irrigation
	Turin	Tertiary treatment	Irrigation and industrial uses
Japan	Tokyo	Tertiary treatment	Irrigation, toilet flushing, and industrial uses
	Chiba Prefecture Kobe City	Tertiary treatment	Irrigation, toilet flushing, and industrial uses
	Fukuoka City	Tertiary treatment	Irrigation, toilet flushing, and industrial uses
Jordan	City of Jordan	Tertiary treatment	Environmental enhancement, irrigation, and industrial uses
Kuwait	Ardhiya, Reqqa, and Jahra,	Tertiary treatment	Irrigation
Mexico	Mexico city	Tertiary treatment	Irrigation
	Monterrey metropolitan area	Tertiary treatment	Industrial uses
Morocco	Ben Slimane	Secondary treatment	Irrigation of golf courses
	Casablanca	Secondary treatment	Irrigation of crops
	DrargaPrject	Tertiary treatment	Irrigation
Namibia	City of Windhoek	Tertiary treatment	Potable reuse
Oman	City of Muscat	Tertiary treatment	Irrigation
	City of Dhofar	Tertiary treatment	Irrigation
	City of Al-Batinat	Tertiary treatment	Irrigation
	City of Salalah	Tertiary treatment	Groundwater recharge
Pakistan	City of Faisalabad	Secondary treatment	Irrigation
Peru	Riyadh North	Tertiary treatment	Irrigation and industrial uses

	Lima	Secondary treatment	Irrigation
	Tacna	Secondary treatment	Irrigation
Saudi Arabia	Riyadh	Tertiary treatment	Irrigation and industrial uses
	Jeddah	Tertiary treatment	Irrigation and industrial uses
Singapore	City of Singapore, NEWater	Tertiary treatment	Industrial and potable water augmentation
Spain	Girona, municipality of Portbou	Tertiary treatment	Landscape irrigation, street cleaning, and fire protection
	Costa Brava (Title 22 reclamation treatment trains)	Tertiary treatment	Landscape irrigation, street cleaning, and industrial use
	Aiguamolls de l'Emporda natural Preserve	Tertiary treatment	Environmental enhancement
	City of Victoria	Tertiary treatment	Irrigation
Tunisia	Great Tunis Area	Secondary treatment	Irrigation
United Arab Emirate	Abu Dhabi	Tertiary treatment	Irrigation
	Al-Ain	Tertiary treatment	Restricted irrigation
United Kingdom	Water Resource Plan for East Anglia	Tertiary treatment	Indirect potable reuse
	Waterwise	Tertiary treatment	Domestic non-potable uses and river flow augmentation
	Beazer Homes District	Tertiary treatment	Car washes, cooling, fish farming, and industrial uses
	Watercycle , Millennium Dome	Tertiary treatment	Toilet and urinal flushing and landscape irrigation
United State of America	Fulton County, Georgia	Tertiary treatment	Golf course and landscape irrigation
	Orange County Water District (Factory 21), California	Tertiary treatment	Ground water recharge
	Irvin Ranch Water District, California	Tertiary treatment	Irrigation and toilet flushing
	City of St. Petersburg, Florida	Tertiary treatment	Irrigation and industrial uses
Yemen	Sana's, Ta'aiz, Al-Hudeidah, and Aden.	Tertiary treatment	Irrigation

Several international wastewater reuse experiences have been proven to help communities meet water demands and alleviate supply challenges without significant health risks if there is significant buy-in by the public and if properly implemented.

3. Wastewater Management in Nigeria

There is a significant lack of proper wastewater treatment in most African countries. Untreated wastewater effluent is one of the most common types of pollution found around urban rivers and in groundwater sources in many African cities (Omosa *et al.,* 2012).

Nigerian cities are expected to participate in the global trend of sustainable environmental improvements or innovations that focus on projects such as water supply and sanitation, solid waste management, air pollution, environmental health, and access to means of livelihood; hence, there is a need for a better understanding of the existing situation of facilities and infrastructures in these cities.

In Aba, one of the Nigeria's commercial cities, Odurukwe (2012), reported that there is no central wastewater system, and there are no septic tanks for domestic wastewater. The sewers for industrial wastewater coming from big industries and the open drains used for the wastewater of medium- and small-scale industries are channeled in such a way that their contents are emptied into Aba River. The pollution of Aba River is very likely to increase in the next decade. There is inadequate or hardly any treatment of the wastewater produced by the industries, and no efforts are being made to change this situation.

In Minna, the capital of Niger state, Idris-Nda *et al.* (2013) reported that domestic wastewater management consists of the use of septic tanks, unplanned and partially planned open drainage systems. In their report, about 35% of domestic wastewater generated goes into the septic tank while the remaining 65% flows freely on ground surface and sometimes forming stagnant pools. The residents in some areas resort to the use of unlined channels to convey wastewater away from their residential areas. A result of this method of disposal is a pool of stagnated water at the terminal end and the production of obnoxious odors.

According to Mustapha (2013), in Kano, Nigeria's third largest city, most of the industries do not have wastewater treatment facilities and thus discharge their untreated effluents into the adjoining receiving water bodies; the receiving water courses are now grossly polluted, and the polluted water courses are being extensively used for water supply, irrigation, fishing, and recreation while the only treatment plant in Kano central is non-functional.

Adesogan (2013) discovered in his study that only Kaduna has a functional industrial wastewater treatment facility (Nigerian Brewery, Kaduna) in the northern part of Nigeria. Similarly, the only functional system in the middle belt is in Abuja, while Benue, Niger, Kogi, Kwara, and Plateau states have non-functional wastewater treatment facilities. Despite the preponderance of wastewater treatment plants in the south, many of the southern States lack functional wastewater treatment systems while some states (Bayelsa, Ondo, Anambra, Ebonyi, Abia, Imo, Cross River, and AkwaIbom) do not have wastewater treatment facilities.

It is disheartening to note that Nigerians still dispose wastewater from domestic areas (washrooms, laundries, and kitchen) directly into surface waters without any treatment. Wastewater from commercial and industrial applications has also experienced the same fate without any plan by most environmental stakeholders to ensure safe disposal. The indiscriminate release of wastewater into the environment in many Nigerian cities has adversely affected sanitation and claimed the lives of many people through diseases such as cholera, hepatitis B, and typhoid (Giwa, 2014). The endocrine-disrupting substances in untreated wastewater can alter the hormone system of human beings, resulting in reproduction predicaments, cancerous growths, and deformations of body organs. In many densely populated areas in Lagos State such as Badagry, Mushin, Oshodi, and Ikorodu, most septic tanks are in dilapidated conditions, leading to severe cases of groundwater contamination. Lagos State alone generates a massive 1.4 trillion cubic centimeters of wastewater every day, according to government statistics (Giwa, 2014).

Change of attitude toward wastewater management is the key to sustainable management of water resources. Government at all levels needs to embrace implementation of wastewater treatment and reuse programs and policies. Without this, the preservation of our water resources and the environment for the future (i.e. sustainability) remains an illusion.

4. Wastewater Reuse Application

Treated wastewater has been used to supplement or replace natural water resources in several ways. The intended reuse application is the major factor influencing the level of treatment needed to protect public health and the environment and the degree of reliability required for the treatment processing and operation (Metcalf and Eddy, 2004). Different end-user classifications have been proposed in the past, and a brief overview of these classifications based on the nature of use, reuse application, and main constraints is presented in Table 2. In broad terms, the major non-potable reuse activities are irrigation (restricted and unrestricted), industrial use, toilet flushing, general cleaning, surface water replenishment, and groundwater recharge. Of the different activities, agricultural irrigation has been identified as the major user in many areas where wastewater is reused. This is mainly because large volumes of water are used in irrigation with relatively lower quality required in comparison to other uses (Yang and Abbaspour, 2007).

Table 2: Categories of wastewater reuse and main constraints (Asano, 1998; Metcalf and Eddy, 2004)

Wastewater reuse categories	**Potential constraints**
1. Agricultural irrigation ● Crop irrigation ● Commercial nurseries 2. Landscape irrigation ● Parks ● School yards ● Freeway medians ● Golf courses ● Cemeteries ● Greenbelts ● Residential	● Surface and groundwater pollution, if not properly managed ● Marketability of crops and public acceptance ● Effect of nutrients, particularly salts, on soil and crops ● Public health concerns related to pathogens (bacteria, viruses, and parasites)
3. Industrial recycling and reuse ● Cooling ● Boiler feed ● Process water ● Heavy construction	● Constituents in reclaimed wastewater may cause scaling, corrosion, biological growth, and fouling ● Public health concerns, particularly aerosol transmission of pathogens in cooling water
4. Ground water recharge ● Ground water replenishment ● Salt water intrusion control	● Organic chemicals in reclaimed wastewater and their toxicological effects ● Total dissolved solids, nitrates, and pathogens in reclaimed wastewater
5. Recreational/environmental uses ● Lakes and ponds ● Marsh enhancement ● Stream flow augmentation ● Fisheries ● Snowmaking	● Health concerns due to bacteria and viruses in the effluent ● Eutrophication in receiving water due to nitrogen and phosphorus ● Toxicity to aquatic life
6. Non potable urban uses ● Fire protection ● Air conditioning ● Toilet flushing	● Public health concerns concerning pathogens transmitted by aerosols ● Effect on scaling, corrosion, biological growth, and fouling ● Potential drinking water and non-potable water cross connection
7. Potable reuse ● Blending in water	● Constituents in reclaimed wastewater, especially trace organic chemicals (mutagenic

supply reservoir ● Pipe to pipe water supply	and carcinogenic) and their toxicological effects ● Aesthetics and public acceptance ● Health concerns about pathogen transmission, particularly viruses

4.1. Wastewater Reuse in Agriculture and Landscape Irrigation

Agricultural irrigation accounts for a third of total withdraws in the United States, 65% worldwide, and about 75% in developing countries (Chaturvedi, 2000). The 16% of the cultivated land that is irrigated worldwide contributes 36% of total food production. The landed areas being irrigated throughout the world in 1940, 1970, and 1995, comprised about 76, 242, and 256 million hectares, respectively. 54% of the irrigated land is in four countries: China (20%), India (19%), the United States (8%), and Pakistan (7%) (Wurbs and James, 2002). Irrigation increases crop yield and the amount of land that can be productively farmed, stabilizes productivity, facilitates greater diversity of crops, increases farm income and employment, helps alleviate poverty, and contributes to national development and economic growth.

Many internationally existing wastewater reuse systems supply treated wastewater for agricultural irrigation as indicated in Table 1. Agricultural reuse is often included as a component in wastewater reuse programs because of the large volumes of water that are required in agricultural irrigation and the beneficial use of the nutrients (nitrogen and phosphorus) present in wastewater, as well as in order to conserve freshwater resources and abate the pollution of freshwater sources resulting in eutrophication.

Wastewater reuse for irrigation is broadly classified into two categories: restricted irrigation and unrestricted irrigation.

4.1.1. Restricted Irrigation

Restricted irrigation is carried out in an area where public access is restricted at any time during or after application of reclaimed water. Water used for restricted irrigation is usually of lesser quality than that of unrestricted irrigation and, as such, secondary treatment with disinfection is satisfactory (Table 3). Human and animal restriction is enforced so as not to compromise public health.

Typical plants irrigated with this quality of water are seed crops, trees, non-recreational parks, food crops not eaten raw, orchards and vineyards, pasture, parks, sports fields, and school grounds. For restricted irrigation, WHO recommends that the treated wastewater should contain no more than one human intestinal nematode egg per liter. The use of sprinkler irrigation is allowed in restricted irrigation of forage crops, drip or trickle systems for vineyard, or orchard crops, while vegetables must be irrigated using subsurface systems.

Table 3: Suggested guidelines for wastewater reuse (USEPA, 2004)

Types of Reuse	**Treatment**	**Reclaimed Water Quality**	**Reclaimed Water Monitoring**	**Setback Distance**
Urban Reuse	Secondary Filtration Disinfection	pH = 6-9 ≤ 10mg/l BOD ≤ 2 NTU No detectable faecal coli/100ml 1 mg/l cl_2 residual (minimum)	pH - weekly BOD - weekly Turbidity - Continuous Coliform – daily Chlorine residue - continuous	15 m to potable water supply wells
Restricted Irrigation	Secondary Disinfection	pH = 6-9 ≤ 30mg/l BOD ≤ 30mg/l TSS ≤ 200 faecal coli/100ml 1 mg/l cl_2 residual (minimum)	pH - weekly BOD - weekly TSS - daily Coliform – daily Chlorine residue - continuous	90 m to potable water supply wells
Unrestricted irrigation	Secondary Advance Disinfection	pH = 6-9 ≤ 10mg/l BOD ≤ 2 NTU No detectable faecal coli/100ml 1 mg/l cl_2 residual (minimum)	pH - weekly BOD - weekly Turbidity - Continuous Coliform – daily Chlorine residue - continuous	15 m to potable water supply wells
Industrial Application	Secondary Advance Disinfection	pH = 6-9 ≤ 30mg/l BOD ≤ 30mg/l TSS ≤ 200 faecal coli/100ml 1 mg/l cl_2 residual (minimum)	pH - weekly BOD - weekly TSS - daily Coliform – daily Chlorine residue - continuous	90 m to potable water supply wells
Groundwater Recharge	Site specific and use dependent	Site specific and use dependent	Depend on treatment and use	Site specific

4.2. Unrestricted Irrigation

Unrestricted irrigation is carried out in an area where public access is not restricted at any time during or after application of reclaimed water. This is due to the high quality of the reclaimed water used for irrigation. Typical plants irrigated with this quality of water include pastures for milking animals, fodder, sports fields, school grounds, food crops eaten raw, lawns, nurseries, and play parks. To irrigate unrestricted access areas, sprinkler and/or drip irrigation can be used while for turf and landscape applications, pop-up sprinklers and spray heads or drip or trickle can be used.

4.2.1. Wastewater Reuse for Industrial Purposes

Industries have been using treated wastewater for cooling, boiler-feed, and process purposes since the early 1990s. The US states of California, Arizona, Texas, Florida, and Nevada have major industrial facilities using reclaimed water for cooling water and process/boiler-feed requirements (USEPA, 2004). Utility power plants are ideal facilities for reuse due to their large water requirements for cooling while petroleum refineries, chemical plants, and metal working facilities could use treated wastewater for their process needs. Treated wastewater reuse potential is presented in Table 4.

Table 4: Potential for wastewater reuse for non-potable purposes in various sectors (Visvanathan and Asano, 2004)

High Potential	**Medium Potential**	**Low Potential**
● Pulp and paper ● Cotton textile ● Glass and steel ● Utility power plants	● Slaughterhouse ● Dairy ● Canning and food processing ● Distillery ● Wool textile ● Photographic processing ● Chemical ● Fertilizer ● Oil refining ● Petroleum ● Electroplating ● Meat processing	● Tanneries and leather finishing ● Pesticide ● Rubber ● Aluminium ● Explosives manufacturing ● Paint manufacturing

4.3. Wastewater Reuse for Urban Activities

Treated wastewater can be used in urban areas for the irrigation of public parks and recreation centers, athletics fields, school yards and playing fields, golf courses, highway medians and shoulders, and landscaped areas surrounding public buildings and facilities; irrigation of landscaped areas surrounding single-family or multi-family residences, commercial areas, office buildings and industrial developments; commercial uses such as vehicle washing facilities, laundry facilities, window washing, and mixing water for pesticides; ornamental landscape uses and decorative water features, such as fountains, reflecting pools, and waterfalls; dust control, block making and laying, and concrete production for construction works; and fire protection through reclaimed water fire hydrants and toilet and urinal flushing (USEPA, 2004).

Using dual reticulation systems (i.e. two systems of pipes conveying potable water and treated wastewater for different uses), treated wastewater is delivered to consumers through a parallel network of distribution pipes separate from the community's potable water distribution system as shown in Figure 1. This reclaimed water distribution system becomes a third water utility, in addition to wastewater and potable water. Reclaimed water systems are operated, maintained, and managed in a manner similar to the potable water system. Dual water systems have been used extensively in countries like Australia (Rouse Hill, Sydney Olympic Park, Aurora Estate, Bluestone Green Estate, Manor Lakes Estate, Melbourne, Pimpama Coomera, Gold Coast, Mawson Lakes, New Haven, and Adelaide) (Radcliffe, 2004) and the US (St. Petersburg, Florida; City of Pomona, California; City of Altamonte Springs, Florida; The Irvine Ranch Water District, California; City of Avalon and California) (USEPA, 2004).

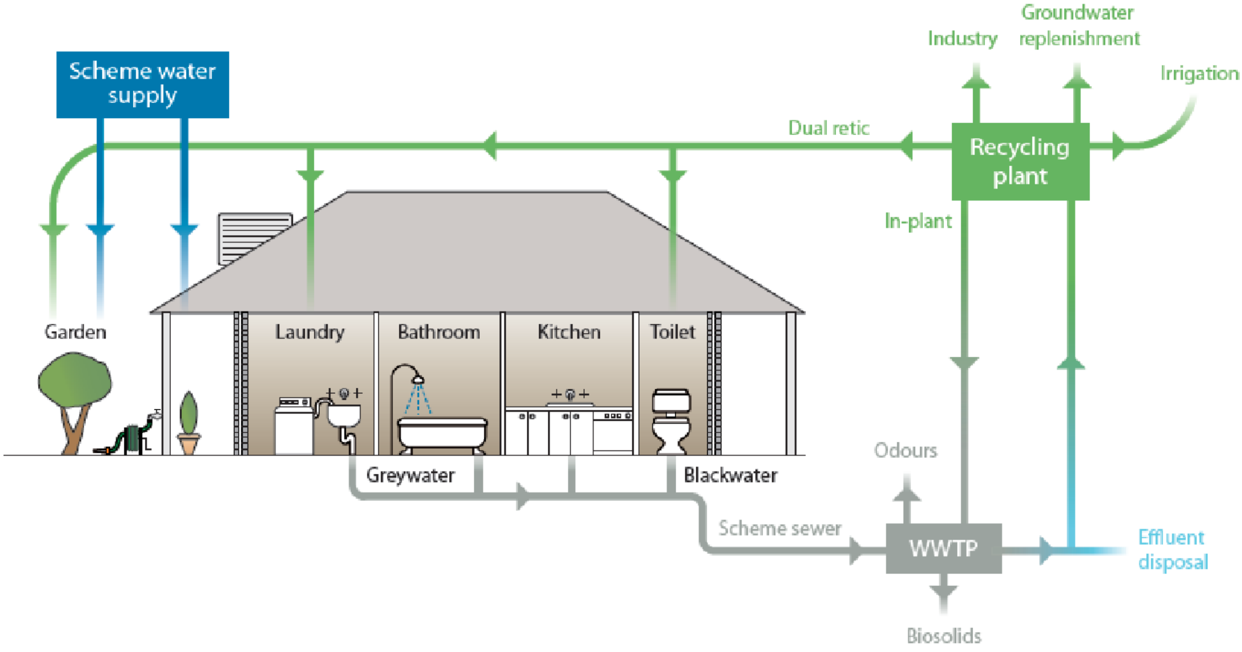

Figure 1: Dual Water reticulation System (Western Australia Water Corporation, 2013)

4.4. Wastewater Reuse for Artificial Groundwater Recharge

Artificial recharge is a process where water is introduced into the sub-surface by anthropogenic means. This procedure can be utilized for the disposal of wastewater or storage and recycling. Artificial Groundwater Recharge (AGR) has for a long time provided means to mitigate depletion of groundwater levels, to protect coastal aquifers from saltwater intrusion, to reduce subsidence, to reduce abstractions from rivers, and to store surface water for future use. Artificial groundwater storage has some advantages over surface water reservoirs that might be costlier, high in evaporation loss, and have a high environmental impact. Also, soil percolation and aquifer storage act as treatment steps with various filtration, adsorption, and degradation processes occurring in the different subsurface horizons, while evaporation as well as taste and odor problems due to algae growth in surface storage are avoided.

The utilization of reclaimed water for AGR is of growing importance and offers additional advantages. Wastewater is an alternative water source available throughout the year, depending on population, industry, and climatic changes; hence, recharge is not limited to periods of surplus surface water. This concept has been in practice in many countries including Australia (Charlesworth *et al., 2002*), Israel (Kanarek and Michail, 1996), Palestine (El Sheik and Hamdan, 2002), and South Africa (Murray *et al.,* 2007).

The concept of AGR offers potential for various uses such as irrigation, industrial process water, and augmentation of urban water supplies. The latter is regarded as indirect potable use.

While there are obvious advantages associated with AGR, some drawbacks include: the extensive land areas that may be needed for spreading basins; prohibitive costs of treatment, water quality monitoring, and operation of injection/infiltration facilities; recharge may increase the danger of aquifer contamination due to inadequate or inconsistent natural treatment; not all recharged water may be recoverable due to movement beyond the extraction well capture zone or mixing with poor-quality groundwater; clogging occurs at the point of recharge which decreases the rate of recharge; uncertainty in aquifer hydraulics; controlled recovery by different users. The concept of whoever stores the water has the right to recover it is generally acceptable throughout the world. It would be highly problematic if there was uncontrolled usage of the stored water; hydrogeology uncertainties, such as transmissibility, faulting, and aquifer geometry, may reduce the effectiveness of the recharge project in meeting water supply demand; inadequate institutional arrangements or groundwater laws may not protect water rights and may present liabilities and other legal problems; and environmental concerns relating to fluctuating groundwater may arise. Artificial recharge could result in groundwater levels being raised above and below the norm, and this can have negative environmental consequences such as affecting groundwater-dependent ecosystems, increased aquifer vulnerability to contamination, and sinkhole formation in dolomitic aquifers (USEPA, 2004; Murray, *et al.,* 2007). These problems can be minimized or eliminated through detailed feasibility studies of the hydraulic and geotechnical properties of the proposed site. The design and construction must be done using sound engineering judgment while adequate financial provision is made for operation and maintenance.

The degree to which these factors might affect the implementation of a groundwater recharge system depends on the management and severity of the site-specific barriers against wastewater reclamation and reuse.

There are two main techniques for artificially recharging wastewater – surface distribution (spreading) or injection. Surface spreading techniques require a detention area (basin, pit, pond, canal, or weir) situated over a permeable unsaturated zone. The detention area is filled with the recharge liquid, which infiltrates through the unsaturated zone to the saturated zone. Injection techniques comprise a well or bore that can introduce recharge liquid into an aquifer or a permeable region of the vadose zone. If conducted by infiltration and percolation through soil and subsoil, the recharge processes, e.g. through the so-called Soil Aquifer Treatment (SAT), offer an additional barrier, particularly for microbial contaminants which are of most concern in any water reuse application. The mixture of reclaimed wastewater with natural groundwater prior to any intended use also positively influences the public acceptance of a reuse scheme.

5. Planning of Wastewater Reuse Projects

Planning of wastewater reuse projects involves a multidisciplinary approach that incorporates the triple bottom line aspects of sustainability. A thorough feasibility study required a multidisciplinary approach by considering several diverse aspects of the proposed project such as technical (e.g. operational efficiency), economic (e.g. life cycle costs), environmental (including public health and safety), and social (public acceptability and legislation) issues. These factors contribute to the final decision that could lead to the success or failure of a dual water reticulation project, and their due consideration should reliably lead to correct decisions. A detailed decision support tool to evaluate the technical, economic, environmental, and social issues has been developed in Adewumi *et al.,* (2010 b) and its application is present in Adewumi *et al.* (2013).

The three major steps that guide the planning of wastewater reuse project as shown in Figure 2 are preliminary investigation, screening of potential markets, and detailed assessment of selected markets for reuse (USEPA, 2004). Each step builds on previous steps until the assessment is complete. USEPA (2004) therefore recommends the following flow process in assessing wastewater reuse projects:

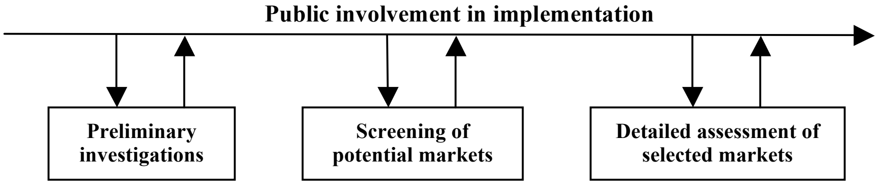

Figure 2: Process of wastewater reuse projects assessment (USEPA, 2004)

5.1. Preliminary Investigation

Preliminary investigations prepare the foundation upon which other investigations are made. It incorporates a wide scope by exploring all possible options in the early planning stage. This is to establish a practical context for thorough assessment of all viable alternatives before settling on the line of action to be taken. At this stage, questions to be asked include (USEPA, 2004):

i. What is the detailed background information of the area under consideration?
i. How sustainable is the present situation of freshwater supply in the area?
ii. What are the present and projected tariffs of freshwater in the area?
iii. Who are the potential consumers (local markets) for the treated wastewater?
iv. What sources of funding are available to support the reuse project?
v. How would wastewater reuse form an integral part of water resources management in the area?
vi. What are the potential environmental impacts of wastewater reuse in the area?
vii. What public health considerations are associated with reuse, and how can these considerations be addressed?

viii. What type of reuse activities are likely to attract the public's interest and support?
ix. What are the existing or proposed laws and regulations that would affect reuse in the area?
x. What local, provincial, or national agencies must review and approve implementation of reuse program?
xi. What are the legal liabilities of a reclaimed water user?

5.1.1. Background Information of the Area

Study area data collection and analysis is fundamental in the feasibility study of any water reuse project. The necessary data to be collected are basic data and characteristics of the area such as landforms, soils, vegetation, topography, etc., as well as climate data, and data pertaining to the water balance of the area, the current water supply situation, and water cost and quality requirement (AQUAREC, 2006).

In order to obtain this information, it is important to contact main stakeholders such as federal government agencies, state government agencies, and local government authorities, industries, water and wastewater agencies, Farmers' Associations, Water Users Associations, etc. It may also be necessary to obtain maps showing locations of water and wastewater facilities, as well as the different water sources, the different land use zones, locations of the possible users of reclaimed water and population distribution, different geological zones, and so on. This may easily be obtained using aerial photographs and Geographic Information Systems (GIS).

5.2. Screening of Potential Markets

An important task at the wastewater reuse project planning stage is to conduct a preliminary market assessment to identify potential treated wastewater users. This involves identifying the location of large and medium water users in order to initiate discussion. On the basis of information gathered in the preliminary investigations, there might be possibilities of implementing a wastewater reuse project for one or more applications in an area. For example, if a large agricultural farm or industry site is located next to a wastewater treatment plant, there is a strong potential for reuse. Users such as these have a high demand for water, and the costs to convey treated wastewater would be low. The cost-effectiveness of providing reclaimed water to a given consumer is highly dependent on the consumer's potential demand (volume required), quality requirements, and the location of the consumer in relation to the source of treated wastewater. It should also be noted that a concentration of smaller consumers (e.g. domestic users) might represent a service area that would be as cost-effective to serve as a single large user.

Once these anchor customers are identified, it is often beneficial to search for smaller customers located along the proposed route of the main distribution pipeline. It is necessary at this stage to determine what portion of total water use might be satisfied by reclaimed water, what quality of water is required for each type of use, and how the use of reclaimed water might affect the user's operations or discharge requirements. This information can be obtained through a questionnaire.

5.3. Detailed Assessment of Selected Markets for reuse

Following the screening of the potential markets, detailed assessment of the selected market must be done. This is a fact-finding stage where technical, economic, social, environmental, and legal/institutional issues are sorted out. A detailed assessment should lead to a thorough assessment of the technical, economic, and financial feasibility of a reuse project. Comparison among alternative reuse programs should be made as well as comparison between the potential reuse projects and alternative water supplies, both existing and proposed. In this phase, economic comparisons, technical feasibility, and environmental assessment activities leading to a detailed plan for reuse might be accomplished.

6. Technical and Environmental Assessment of a Wastewater Reuse Project

One of the key considerations in any reuse project is the technical viability of the project. This factor is a fulcrum in the decision-making regarding the implementation of any wastewater reuse project. The possible constraints include understanding the treatment requirements for producing safe and reliable treated wastewater that is suitable for its intended applications; resource requirements (land, civil works, installation of pipelines, storage tanks, energy, human resources, etc.) and identification of the knowledge, skills, and abilities necessary to operate and maintain the proposed system (USEPA, 2004; AQUAREC, 2006).

6.1. Treatment Requirements to meet Reuse Quality

One of the major critical issues for consideration in a water reuse project is to ensure that public health is not compromised through the use of treated wastewater. This is achieved by safe delivery and proper use of the treated wastewater. Protection of public health is achieved by reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in the reclaimed water, controlling chemical constituents in reclaimed water, and/or limiting public exposure (contact, inhalation, ingestion) to reclaimed water (USEPA, 2004).

Potential health risks will vary depending on the reclaimed water applications and the level of human exposure. Where human exposure is likely in a reuse application, reclaimed water should be treated to a high degree prior to its use. Conversely, where public access to a reuse site can be restricted so that exposure is unlikely, a lower level of treatment may be satisfactory, provided that worker safety is not compromised. Determining the necessary treatment for the intended reuse application requires an understanding of: the constituents of concern in wastewater; level of treatment and processes applicable for reducing the constituents to levels that achieve the desired reclaimed water quality; reliability of and risks attached to the different levels of treatment; and the reticulation infrastructure which will be used to convey, treat, and/or store wastewater.

6.1.1. Constituents of Reclaimed Water

Reclaimed wastewaters contain two general types of hazards for humans. The first is microbial contaminants, largely present in fecal waste and which have potential to cause outbreaks of viral, bacterial, and parasitic diseases. Untreated municipal wastewater contains varying levels of pathogens including bacteria, viruses, protozoa, and helminths. The second risk comes from various chemicals, including pharmaceutical products that end up in wastewater. This may cause a range of ill effects should people be exposed to them for prolonged periods of time. Environmental contaminants, industrial chemicals, domestic chemicals, and pharmaceuticals can also affect treated effluent composition. Both sets of hazards require sound risk management systems for effective control (Radcliffe, 2004).

The important constituents of concern in municipal wastewater, subject to treatment, are classified as conventional, non-conventional, and emerging. Typical constituents included under each category are described in Table 5.

The term “conventional” is used to define constituents that serve as the basis for the design of most conventional treatment plants. “Non-conventional” is used to describe constituents that may be removed or reduced using advanced wastewater treatment processes before the water can be used beneficially. The term “emerging” describes classes of compounds that may not be removed effectively with advanced treatment. Although there is little or no information concerning health or environmental effects, some of the compounds that have been identified in reclaimed water are known to have both acute and chronic health effects, depending on their concentrations and exposure pathways (Metcalf and Eddy, 2004).

Table 5: Classification of typical constituents found in wastewater (Metcalf and Eddy, 2004)

Classification	**Constituents**
Conventional	Total suspended solids Colloidal solids Biochemical oxygen demand Total organic carbon Ammonia Nitrate Nitrite Total nitrogen Phosphorus Bacteria Protozoa Viruses
Non-conventional	Refractory Organics Volatile organic compound Surfactants Metals Total dissolved solids
Emerging	Prescription and non-prescription drugs Home care products Veterinary and human antibiotics Industrial and household products Sex and steroidal hormones Other endocrine disrupters

6.1.2. Levels of Treatment Required for different Applications

Depending on the composition of the wastewater to be treated and on the required reclaimed water quality, the treatments and systems will differ. In Table 6, different treatment trains are proposed depending on the reclaimed water application (Lazarova, 2001). Usually, intensive treatments are more expensive, require advanced technologies, and require less space compared to extensive ones.

Levels of wastewater treatment are generally classified as preliminary, primary, secondary, and advanced. Advanced wastewater treatment, sometimes referred to as tertiary treatment, is generally defined as any treatment beyond secondary. A generalized wastewater treatment option for various reuses is shown in Figure 3. Jhansi and Mishra (2013) discusses sustainable wastewater treatment systems in the context of urban areas of the developing world.

Table 6: Recommended treatment schemes as a function of wastewater reuse applications (Lazarova, 2001)

Reuse Application Type	**Extensive Treatment (E)**	**Intensive Treatment (I)**
1. Irrigation of restricted crops	E.1. Stabilization pond in series or aerated lagoons; wetland; infiltration - percolation	I.1. Secondary treatment by activated sludge or trickling filter with or without disinfection
2. Irrigation of unrestricted crops, vegetables eaten raw	E.1. Same as E.1. with polishing steps and storage reservoir	I.2. Same as I.1. with tertiary filtration and disinfection
3. Urban uses for irrigation of parks, sport fields, golf courses	E.3. Same as E.2.	I.3. Same as I.2. with filtration in the case of unrestricted public access
4. Groundwater recharge for agricultural irrigation	E.4. Same as E.2. completed by soil-aquifer treatment	I.4. Same as I.2. with nutrient removal (when necessary)
5. Dual distribution for toilet flushing	E.5. Not applicable	I.5. Same as I.3. with activated carbon (when necessary) or membrane bioreactors and disinfection
6. Indirect and direct potable use	E.5. Not applicable	I.6. Secondary, tertiary, and quaternary treatment including activated carbon, membrane filtration (including reverse osmosis), and advanced disinfection

6.1.2 Treatment Reliability

Because of the potential harm that could result from the delivery of improperly treated reclaimed water to the user, a high standard of reliability is required at wastewater treatment plants. Water reuse requires strict compliance with all applicable reclaimed water quality parameters. The need for reclamation facilities to reliably and consistently produce and distribute reclaimed water of adequate quality and quantity is essential and dictates that careful attention be given to reliability features during the design, construction, and operation of the facilities.

In reclaimed water reliability assessments, close monitoring of all elements that make up a water reclamation system is imperative. These elements include power supply, individual treatment units, mechanical equipment, the maintenance program, and the operating personnel. Critical units in the water reclamation system include the disinfection unit, power supply, and various treatment unit processes.

According to USEPA, (2004), reliability of water reuse should also consider the followings:

i. Operator certification to ensure that qualified personnel operate the water reclamation and reclaimed water distribution systems
ii. Instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions
iii. A comprehensive quality assurance program to ensure accurate sampling and laboratory analysis protocol
iv. Adequate emergency storage to retain reclaimed water of unacceptable quality for retreatment or disposal
v. Supplemental storage to ensure that the supply meets user demand
vi. A strict industrial pretreatment program and strong enforcement of sewer use ordinances to prevent illicit sewage of hazardous materials that may interfere with the intended use of the reclaimed water; and
vii. A comprehensive operating protocol that defines the responsibilities and duties of the operations staff to ensure the reliable production and delivery of reclaimed water.

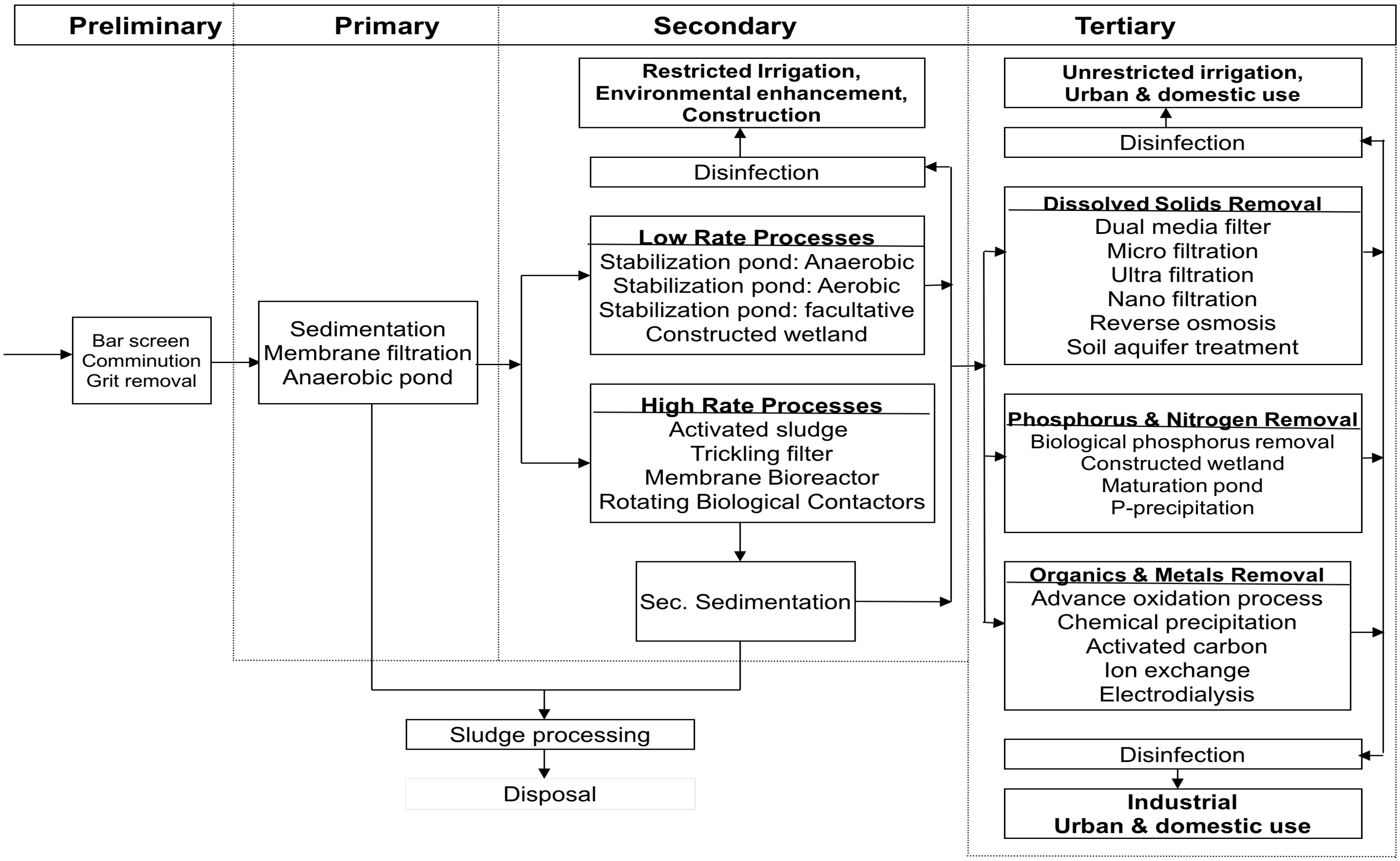

Figure 3: Wastewater treatment options for various reuse applications (USEPA, 2004; Adewumi *et al.,* 2012)

7. Risk Analysis

Risks are closely related to the treated wastewater quality and the reuse application of the water. Risk analysis is used to analyze health implications of an action on humans and the environment. Typically, risk analysis is divided into two parts, risk assessment and risk management (Metcalf and Eddy, 2004). Risk assessment involves the study and analysis of the potential of certain hazards to human health and environment, while risk management is the process of reducing risks that are deemed unacceptable (Figure 4).

Both human and environmental risk assessments take place in four major steps in sequential order as follows: hazard identification, dose (concentration) – exposure (effect) assessment, risk characterization, and risk management (Metcalf and Eddy, 2004; AQUAREC, 2006).

Hazard identification involves weighing the available evidence and determining whether a substance constitutes/exhibits a particularly adverse health hazard. This is usually carried out by gathering evidence on the potential for the substance to cause adverse health effects in humans or unacceptable environmental impacts. Exposure is the process by which an organism comes in contact with the substance. Dose response assessment defines a relationship between the amount of toxic constituents to which a human is exposed and the risk that there will be an unhealthy response to that dose. Exposure is the link between hazard and risk. Risk characterization is the last step in risk assessment, in which the questions of who is affected and what are the likely effects are defined for further investigation. Risk management involves the development of standards, guidelines, and management strategies for specific constituents of hazardous influence on human health and environment (Metcalf and Eddy, 2004; Adewumi *et al.,* 2012).

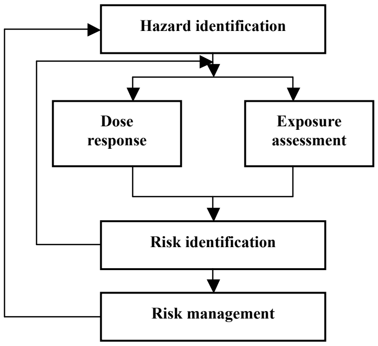

Figure 4: Risk assessment process and risk management (Metcalf and Eddy, 2004)

8. Treated Wastewater Reticulation

The major concern guiding design, construction, and operation of a reclaimed water distribution system is the prevention of cross-connections. A cross-connection is the point in a distribution system where a potable water system is connected to a non-potable system or a system of questionable water quality. Another major concern is the wrong use of reclaimed water. To protect public health from the onset, a reclaimed water distribution system should be accompanied by health codes, pipe color codes, procedures for approval (and disconnection) of service, regulations governing design and construction specifications, inspections, and operation and maintenance staffing. According to USEPA (2004), the Public health protection measures that should be addressed in the planning phase are:

i. To establish that public health is the main concern, as well as to devise procedures and regulations to prevent cross-connections,
ii. To develop a uniform system to mark all non-potable components of the system,
iii. To prevent improper or unintended use of non-potable water through a proactive public information program,
iv. To provide for routine monitoring and surveillance of the non-potable system,
v. To establish and train special staff members to be responsible for operations, maintenance, inspection, and approval of reuse connections, and
vi. To develop construction and design standards and provide for the physical separation of the potable water, reclaimed water, sewer lines, and appurtenances.

9. Recommendations for Establishing a Wastewater Reuse Programme in Nigeria

In planning a wastewater reuse program in Nigeria, the first step is the implementation of a sound research program directed and funded by the Federal Ministry of Water Resources. Universities, polytechnics, and research institutions, including private organizations, can take part in such nation-wide projects through which the base data survey of wastewater generation, collection, treatment, and storage can be undertaken in the urban areas of the country.

There is a need for total water supply inventory from which the volume of wastewater produced per capita per day can be established. Research programs will also establish accurate knowledge of the various wastewater pollutants in our environment. The data obtained will be most useful in the formulation of the appropriate policies in the disposal of wastewater and the planning for reuse after different levels of treatment.

As wastewater treatment is relatively expensive (far more than water supply treatment) pilot programs and projects must first be established after detailed feasibility studies are conducted in selected locations to determine the efficacy of nation-wide programs for wastewater reuse. Starting point could be in the Northern parts of Nigeria where there exist vast arable lands for irrigation due to low annual rainfall (< 700mm) and high atmospheric temperatures (>35^{o}C). This will enable farmers to increase their output and cultivate year-round rather than seasonally during raining season (maximum of 7 months per of the year). This will boost the national agricultural output and enhance food security. It will also create employment for the teeming population while at the same time increasing the national GDP and improving the economy.

It is also necessary that the government formulate policies targeted at stiffening water permits for industrial and agricultural use to encourage wastewater reuse. Water tariff for the industrial, agricultural, and commercial sectors can also be increased to encourage reuse.

For any new program or policy, there is a need for enlightenment of the populace. Wastewater reuse programs are even more acute as they will involve some potential conflicts with cultural practices, even though most people do not know that the water they use is seriously contaminated by wastewater in various forms.

Any reuse program must involve the related ministries, departments, and agencies dealing with the environment such as the Federal Environmental Protection Agency (FEPA), the Federal Ministry of Environment, Housing and Urban Development, State Water Corporations, and Sewage Disposal Agencies to increase levels of success.

9. Conclusion

As wastewater reuse is gaining global attention, the success of any reuse project largely depends on the criterion that cuts across technical, economic, and environmental factors that supports sustainability. Positive community perceptions toward recycled water use have been identified as a key component of wastewater reuse project success. It is widely recognized that the following factors highly influence public acceptance of treated wastewater reuse: perceived health risk, political issues, and the degree of human contact with treated wastewater (Adewumi *et al.,* 2014). For the purpose of developing strategy and policy, perception studies are required in each national and even sub-national context because of large variations in culture, climate, water availability, economy, etc. (Friedler *et al.,* 2006). Such variability makes the transferability of specific findings and conclusions from one country to another somewhat difficult. Also, many wastewater treatment schemes are not successful in developing countries because they are simply copied from Western treatment systems without considering the appropriateness of the technology for the culture, land, and climate. Often local engineers educated in the Western development programs have supported the choice for inappropriate systems. Many of the implemented installations were abandoned due to the high cost of running the system and repairs. As a starting point on the planning and implementation of treated wastewater reuse in Nigeria, this paper presents a comprehensive guide for the formulation of a necessary policy and program that could guide the Federal Ministry of Water Resources for the successful integration of wastewater reuse program as part of the National Integrated Water Resources Management Mechanism.

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