Application of Reclaimed Water for Irrigation: A Review

by

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Major Paper

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1. Introduction

The availability and quality of water is one of the major environmental challenges of the 21st century due to a rapid increase in population, industrialization, agricultural practices, and urbanization. A considerable change has been observed in global hydrological cycles due to climate change and socioeconomic development significantly affecting water resources and aquatic life [1, 2] Moreover, surface and groundwater supplies are disturbed due to changes in precipitation and runoff along with changes in consumption and withdrawal and these trends are expected to continue which will lead to water shortages in many areas. Given the stress on water resources, California drought and Cape town, South Africa 'Day zero' are examples of critical water crisis the world may encounter if water conservation and alternative reuse and production methods are not developed in time [3, 4]. Many countries are struggling to balance water use among municipal, industrial, agricultural, recreational and natural resources. In order to fulfill demand, there has been a growing interest in developing alternative water sources, such as desalinized brackish water, seawater, and reclaimed water. Recycled or reclaimed water refers to treated wastewater after removing solids and certain impurities, that can be further used for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin [5].

Due to population growth, increased urbanization, water scarcity, and water availability due to climate change are increasing pressure on water supply. The population growth is expected to increase from 7.2 billion to 9.6 billion by 2050. This population growth and climate variability are damaging the natural water cycle and various problems are emerging such as instability of river flow, drying of spring water and deterioration of the ecosystem [6-8]. Thus, recycled or reclaimed water is considered as an alternative source of water supply in water-limited regions. Reclaimed water or recycled water is the water recovered from domestic, municipal, and industrial wastewater treatment plants that has been treated to meet specific water quality criteria with the intent of being used for a range of purposes [9] (Figure 1). Therefore, reclaimed water is of immense benefit in non-potable reuse such as agricultural and landscape irrigation, industrial applications, recreational activities, environmental applications (surface water replenishment and groundwater recharge), urban cleaning, firefighting, construction, etc. [10]. Worldwide, about 7.1 billion m^3/year (5% of treated wastewater and 0.18% of water consumption) are reused mainly for irrigation (about 50%) and industrial purposes (about 20%) [11]. Since municipal wastewater is low in pollutants compared to industrial wastewater discharges. It has low risk of environmental impact on conventional water supply, and has minimal environmental impact over conventional water supply; is an attractive alternative approach to conserve water resources. Approximately, 7 percent of municipal wastewater is recovered for its further reuse and 56.4% of the reclaimed water (about 1.2 billion gallons) is utilized for irrigation purposes (Figure 1).

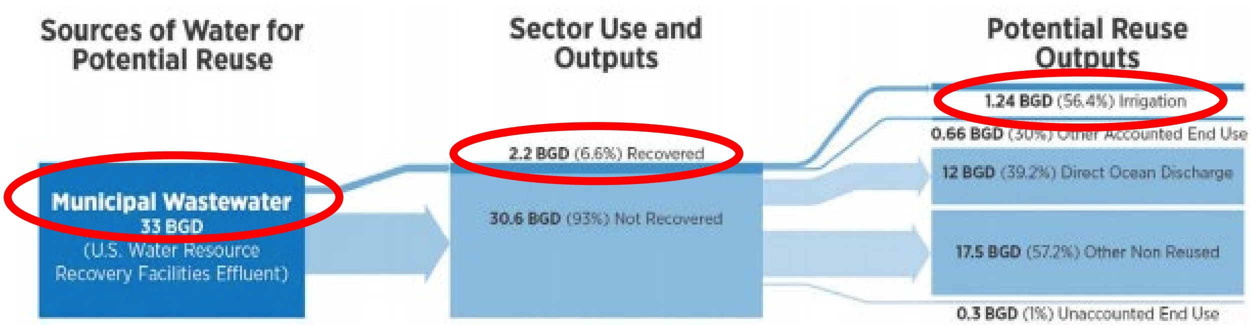

Figure 1: Municipal wastewater and its potential reuse categories. Figure modified from USEPA (2019).

More specifically, municipal wastewater is reused to irrigate golf courses, lawns, landscaping, forests, and even crops in many communities in the U.S. and around the world. Over the last several decades, reclaimed water use for irrigation has been considered a common practice worldwide due to advantages such as pressure alleviation on other water resources, year-round reliability, nutrient recovery to crops, and decreased disposal costs [12]. Furthermore, use of reclaimed water for agriculture has been widely supported by regulatory and institutional policies. For example, California (CA), Florida (FL), and Texas (TX) are the top recycled water users because of utilization of reclaimed water for agricultural irrigation. In addition, states including Arizona (AZ), Nevada (NV), Colorado (CO, North Carolina (NC), and Utah (UT) depend significantly on water reuse for irrigation in order to conserve ground water and surface water (Figure 2). Water CONSERV II project in Orange County, FL is one of the largest reclaimed water projects where farmers have been using reclaimed water to irrigate citrus since 1986 (USEPA, 2012). Haering et al. 2009 reported that in 2005, FL used recycled water to irrigate over 56,000 acres of land (covering 462 golf courses) and 201,465 residential gardens, 572 parks and 251 schools [13]. Similarly, California received a significant increase in recycled water demand (from 400 to 862 Mm^3/year) within two decades (from 1989 to 2009). In CA, State Water Resources Control Board (SWRCB) estimated that recycled water demand to reach 3 milliom ac-ft/yr by

2030, therefore, CA currently recycles about 650,000 ac-ft/yr (800 MCM/yr) to be used mainly for agriculture irrigation [14]. Another major user of reclaimed water use in irrigation is Texas where reclaimed water has been used to irrigate cotton, grain sorghum, and wheat since 1938 [9].

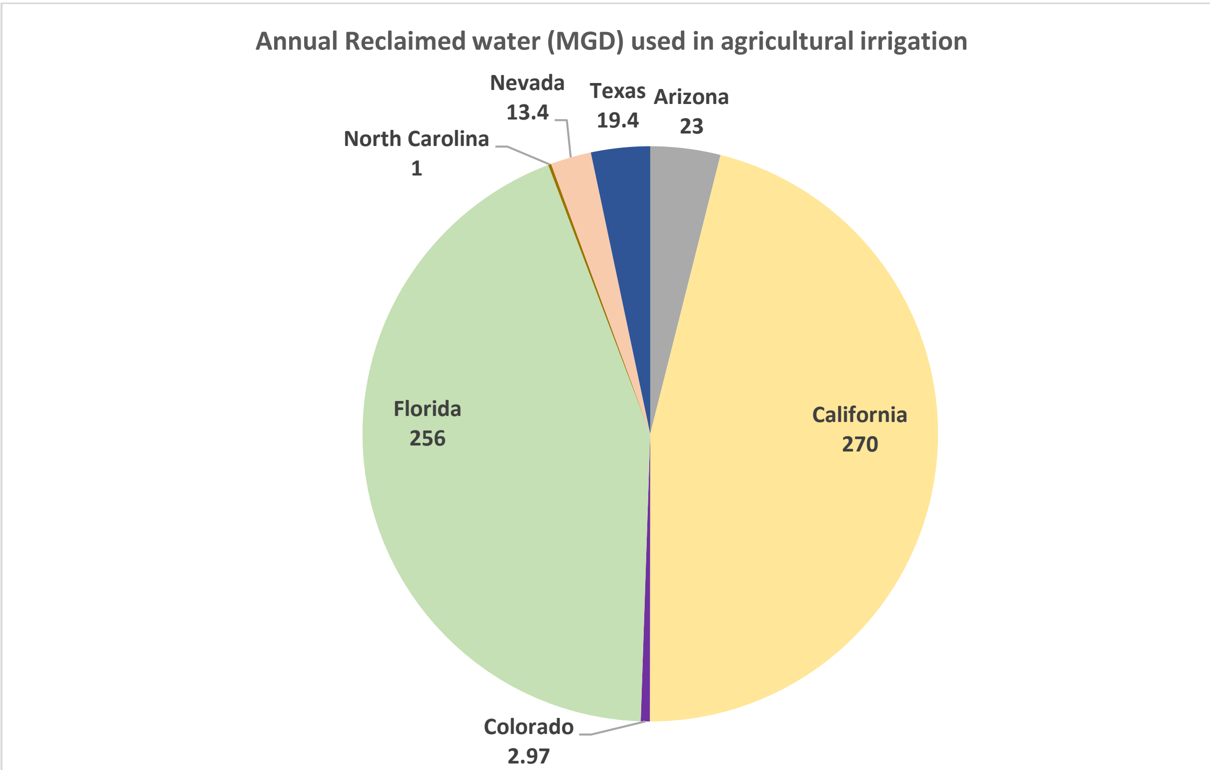

Figure 2: The use of recycled water for agricultural irrigation by major US states (Data obtained by Byrk et al., 2011).

Moreover, reclaimed water quality as well as demand for irrigation varies depending on the application if water is needed for irrigating food crops or golf courses. In order to understand water demand for agricultural or landscape irrigation, analysis was performed for the five major states (AZ, NV, UT, CA, and FL). Water use estimate data for the year 2015 was downloaded from U.S. Geological Survey's National Water Use Project [15]. Interestingly, again CA and Fl were found to be major user of reclaimed water for irrigation including golf course irrigation (Figure 3). However, TX was not included in the present analysis because of not availability of data for the year 2015.

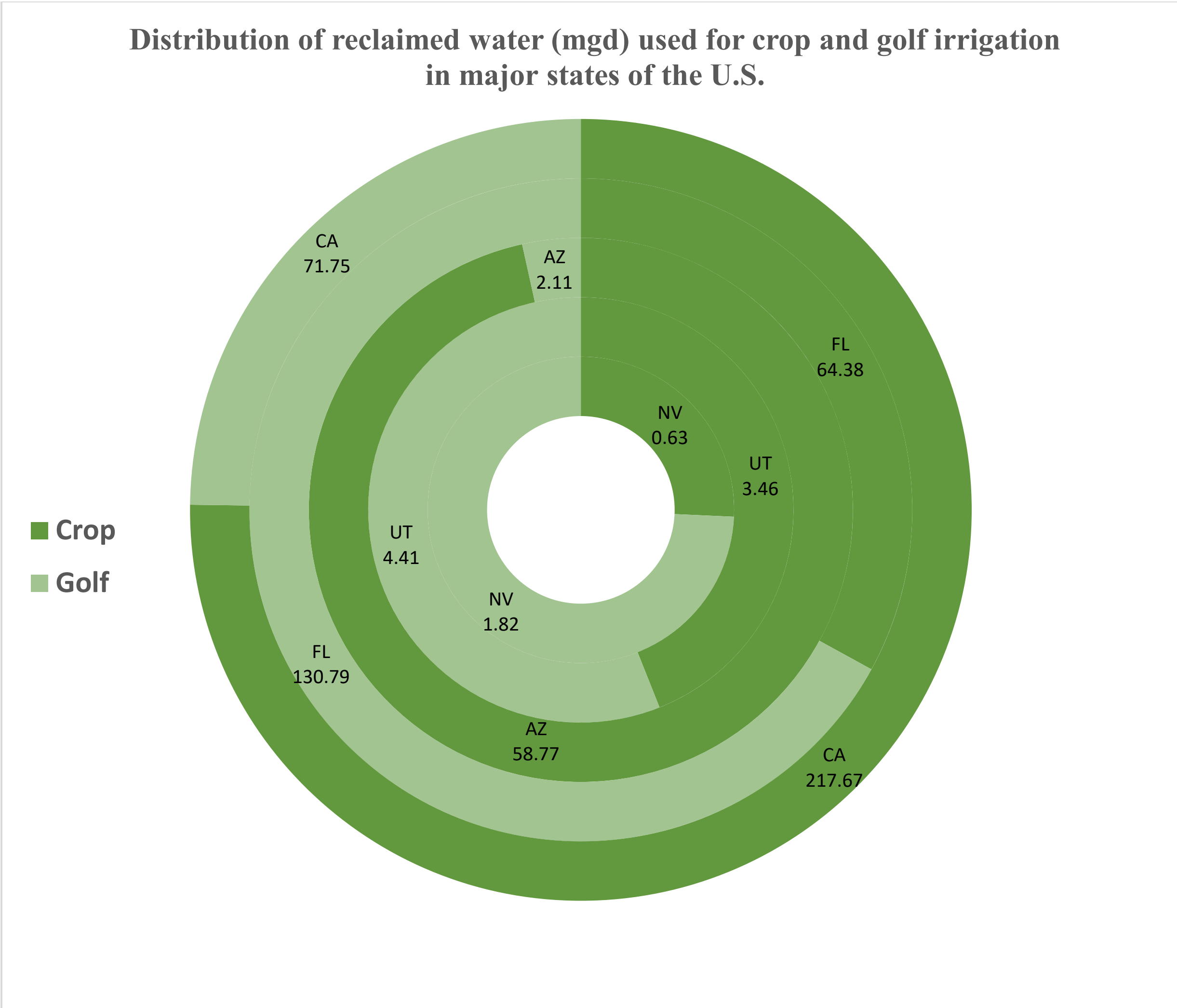

Figure 3: Use of reclaimed water for food crops and non-crops irrigation in the U.S. in 2015 (Data downloaded from USGS https://www.sciencebase.gov/catalog/item/5af3311be4b0da30c1b245d8).

Despite the benefits of recycled water, there have been a great concern about associated health risks and environmental impacts with reclaimed water to be used for irrigation throughout the world. Therefore, it is essential to monitor reclaimed water application for irrigation which may create undesirable effects in soils and plants with direct effects on soil suitability for cultivation and water resource availability [16, 17]. In order to meet minimum water quality and environmental regulations and for the desired reuse application, wastewater requires a suitable treatment method for removal of certain contaminants. Here in this paper, we review treatment strategies and water reuse regulations for irrigation.

2. Global demand for reclaimed water

The global freshwater resources are being depleted and polluted and eventually threatening the sustainable development and ecosystem health. In the U.S, San Francisco was the first city to begin water reclamation in 1932. The city instituted a small system in the Golden Gate Park, irrigating natural areas in need of moisture. Later, Tallahassee in Florida began exploring the water reuse and reclamation in 1966. Later, the water reuse system has been expanded in St. Petersburg (1977), Orlando, Florida (1985) for irrigation. Several research projects were conducted to ensure the water quality due to chemicals or pathogens, however, interestingly, the studies concluded no adverse impact on public health and safety (http://www.mwwatermark.com/en_US/overview-of-the-history-of-water-reuse-2/).

Other than United States, severe water stress in many arid and semi-arid regions of the world such as Middle East and North Africa (MENA) need alternative unconventional water resources to meet the demand. However, in the MENA countries, wastewater is discharged without or poorly treatment, therefore, wastewater utilization in the MENA region is very low which necessitates to implement the new concepts, policies and measures for sustainable water supply and management [7, 18]. As a result of water scarcity, several countries such as Israel, Jordan, and Tunisia, wastewater is becoming a preferred source of water [19-21]. Moreover, developing countries are implementing water reuse practices, for example, China has been using reclaimed water to satisfy the increasing water demand for domestic uses and irrigation. In Beijing, 680 million tons of reclaimed water from the municipal wastewater was reused in 2010, accounting for 19.3% of its total annual water consumption [22]. Furthermore, Chen et al. (2015) investigated the soil health in order to understand the effects of reclaimed water used for irrigation the urban areas. The study concluded that the soils became healthier with longer reclaimed water irrigation; soil total nitrogen, available phosphorus and organic matter content increased by 6–17% and no significant change of soil pH was observed [23].

3. Water quality guidelines of recycled water for use in irrigation

There are standard guidelines established by USEPA in order to protect human health and water quality, however, states are encouraged to develop their own regulations to reduce disease risks associated with wastewater. Reclaimed water must meet certain treatment standards to remove salts, chemical contaminants and pathogens that are potentially detrimental to soils or plant growth and pose a risk to the environment and public health. According to USEPA, recycled water for five constituents namely, pH, biochemical oxygen demand (BOD), total suspended solids (TSS), turbidity (measured in nephelometric turbidity units, or NTUs), fecal coliform and residual chlorine must be monitored and should fall in the given range (Figure 4). BOD indicates the presence of reactive organic matter in water while TSS or turbidity represents the amount of organic and inorganic particulate matter in water. High suspended solids (TSS) concentrations may result in reduced drainage because it may clog irrigation systems. The TSS levels less than 50-100 mg/L are considered as safe for drip irrigation.

Some other parameters such as fecal coliform or enterococci typically indicate the pathogenic contamination and requires longer treatment (disinfection) to assure that viruses and parasites are inactivated or destroyed. In order to get rid of microorganisms, advanced disinfection is required which may increase the free chlorine concentration and ultimately damage plants at a high concentration of 5 mg/L or more. Additionally, pH indicates the presence of phytotoxic ions and the recommended pH should be between 6.5 – 7.0. The concentration of bicarbonates (>120 mL) and carbonates (>15 mg/L) may cause white lime deposits on plant leaves, and is responsible for increase in soil pH and decrease permeability. Due to the significant impact of each component on plants and humans, each constituent of reclaimed water should be assessed before its intended use (Figure 4).

Reuse Category	Treatment	Water Quality	Monitoring	Setback
***Food Crops* 15** The use of reclaimed water for surface or spray irrigation of food crops which are intended for human consumption, consumed raw.	▪ Secondary (4) ▪ Filtration (5) ▪ Disinfection (6)	▪ pH = 6.0-9.0 ▪ ≤ 10 mg/l BOD (7) ▪ ≤ 2 NTU (8) ▪ No detectable fecal coliform/100 ml (9,10) ▪ 1 mg/l Cl_2 residual (min.) (11)	▪ pH – weekly ▪ BOD - weekly ▪ Turbidity - continuous ▪ Fecal coliform - daily ▪ Cl_2 residual – continuous	▪ 50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media (18)
Processed Food Crops* 15** The use of reclaimed water for surface irrigation of food crops which are intended for human consumption, commercially processed. ***Non-Food Crops The use of reclaimed water for irrigation of crops which are not consumed by humans, including fodder, fiber, and seed crops, or to irrigate pasture land, commercial nurseries, and sod farms.	▪ Secondary (4) ▪ Disinfection (6)	▪ pH = 6.0-9.0 ▪ ≤ 30 mg/l BOD (7) ▪ ≤ 30 mg/l TSS ▪ ≤ 200 fecal coli/100 ml (9,13, 14) ▪ 1 mg/l Cl2 residual (min.) (11)	▪ pH – weekly ▪ BOD - weekly ▪ TSS - daily ▪ Fecal coliform - daily ▪ Cl_2 residual – continuous	▪ 300 ft (90 m) to potable water supply wells ▪ 100 ft (30 m) to areas accessible to the public (if spray irrigation)

Figure 4: USEPA guidelines for use of reclaimed water for irrigation (Taken from USEPA, 2012)

Above-mentioned guidelines are given by EPA; however, guidelines vary considerably from state to state. States such as California and Florida compile comprehensive guidelines for specific reuse application by the California Water Resources Control Board (CWRCB) in Sacramento and the Florida Department of Environmental Protection (FDEP) in Tallahassee, respectively. A comparison of treatment/disinfection requirements for urban reuse (irrigation of residential properties, golf courses, and other areas accessible to the public) and for irrigation of edible food crops is given in the table 1 for CA and FL.

Table 1: Comparison of California and Florida guidelines for water reuse.

Parameter	**Unrestricted urban reuse**		**Restricted urban reuse**		**Agricultural food crops**		**Agricultural non-food crops**	
	CA	**FL**	**CA**	**FL**	**CA**	**FL**	**CA**	**FL**
Treatment	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and	Secondary – 23, oxidized, and disinfected	Secondary treatment, filtration, and	Oxidized, coagulated, filtered, and dis infected	Secondary treatment, filtration, and high-	Secondary - 23, Oxidized,	Secondary treatment, basic disinfection

		high- level disinfection		high- level disinfection		level dis infection	and disinfected	
BOD_5	Not Specified	20 mg/l $CBOD_5$	Not Specified	20 mg/l $CBOD_5$	Not Specified	20 mg/l $CBOD_5$	Not Specified	20 mg/l $CBOD_5$
TSS	NS	5.0 mg/l	Not Specified	5 mg/l	Not Specified	5.0 mg/l	Not Specified	20 mg/l
Turbidity	2 NTU (Avg)	Not Specified	Not Specified	Not Specified	2 NTU (Avg)	Not Specified	Not Specified	Not Specified
	5 NTU (Max)				5 NTU (Max)			
Coliform	Total	Fecal	Total	Fecal	Total	Fecal	Total	Fecal
	2.2/100 ml (Avg)	75% of samples below detection	23/100 ml (Avg)	75% of samples below detection	2.2/100 ml (Avg)	75% of samples below detection	23/100 ml (Avg)	200/100 ml (Avg)
	23/100 ml (Max in 30 days)	25/100 ml (Max)	240/100 ml (Max in 30 days)	25/100 ml (Max)	23/100 ml (M ax in 30 days)	25/100 ml (Max)	240/100 ml (Max in 30 days)	800/100 ml (Max)

In general, the guidelines are consistent with EPA, however, Florida requires secondary treatment, filtration, and high-level disinfection for urban and agricultural irrigation except for non-food crops.

4. Wastewater treatment methods to produce reclaimed water

Domestic wastewater is collected at a wastewater treatment facility from households, schools, offices, hospitals, and commercial and industrial facilities. This wastewater undergoes several stages of treatment to prepare the water for reuse or discharge into the environment to ensure that reclaimed water is safe and reliable for its intended use (Figure 5).

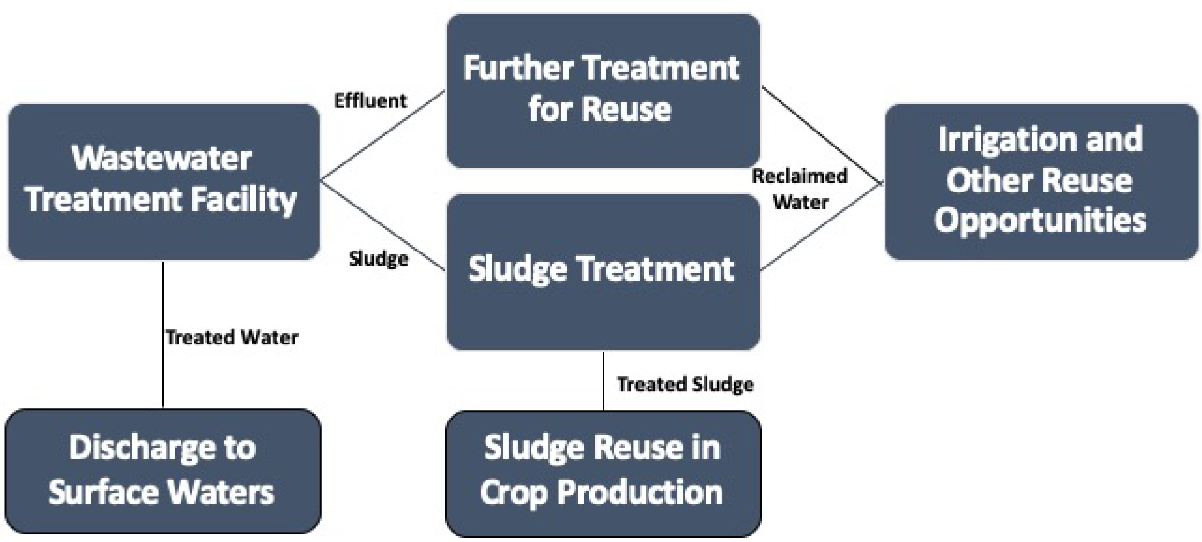

Figure 5: Prospects of wastewater at a wastewater treatment facility.

In general, wastewater contains mainly organics, dissolved solids, suspended solids, nitrogen, phosphorus, chlorides/salts, and metals. The treatment methods are designed on the basis of type of wastewater contaminants and reuse application. The methods include primary, secondary, and sometimes advanced treatment processes, with different biological, physical, and chemical technologies such as activated sludge treatment, sequencing batch reactor, membrane filtration and biological treatment to produce higher quality water (Figure 6). The primary treatment involves removal of solid waste materials while secondary treatment is done to treat wastewater in order to remove or degrade any remaining wastes still suspended in the water. Tertiary treatment is the final stage treatment that involves advanced removal of harmful chemicals and disinfection to kill pathogenic organisms.

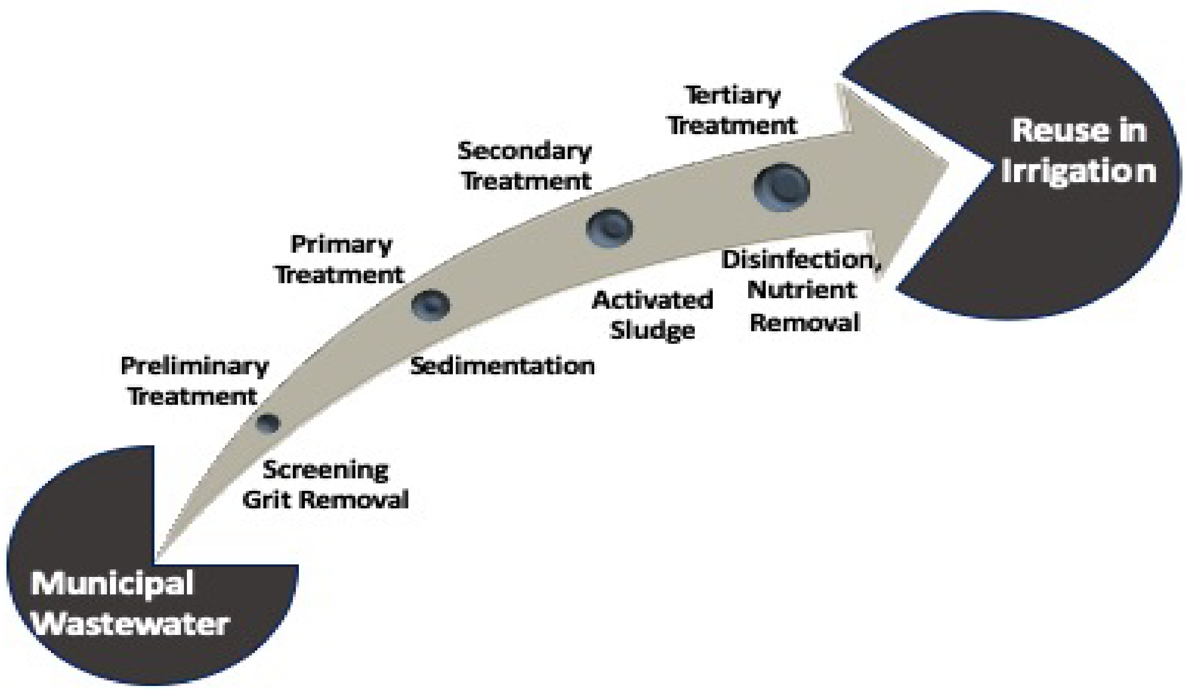

Figure 6: General overview of the treatment levels in order to produce water for reuse.

Typically, secondary treatment and disinfection is the minimum level of treatment required for unrestricted irrigation of urban landscapes. However, in some cases, additional treatment including coagulation, oxidation, and filtration are practiced. Monitoring for specific pathogens (Giardia and Cryptosporidium) and microconstituents in the wastewater require the close monitoring and advanced treatment systems because the chemicals present in pharmaceutical and personal care products are known to be endocrine disrupting compounds. Such compounds may have the potential to cause reproduction system abnormalities and immune system malfunctioning in wildlife and humans at higher concentrations because fish, amphibians, and birds have been found to develop reproductive system abnormalities upon direct or indirect exposure to a variety of endocrine disrupting compounds. However, the impacts of the extremely low concentrations of these compounds found in wastewater effluent or reclaimed water are still unknown. Nevertheless, wastewater containing such compounds is further treated with ozone, hydrogen peroxide, and UV light to destroy some microconstituents via advanced oxidation. Figure 7 illustrates the flowchart shows a typical treatment sequence to produce reclaimed quality water. Primary treatment is a front-end treatment (preliminary treatment and primary clarification) that reduces the contaminants to manageable levels for further reduction in secondary treatment. The secondary treatment is typically an aeration basin and secondary clarification, which reduces the contaminants to a target reclaimed water limit. The final tertiary treatment is a final polishing step which typically aims at reducing suspended solids, and disinfection before it reaches a reclaimed water quality.

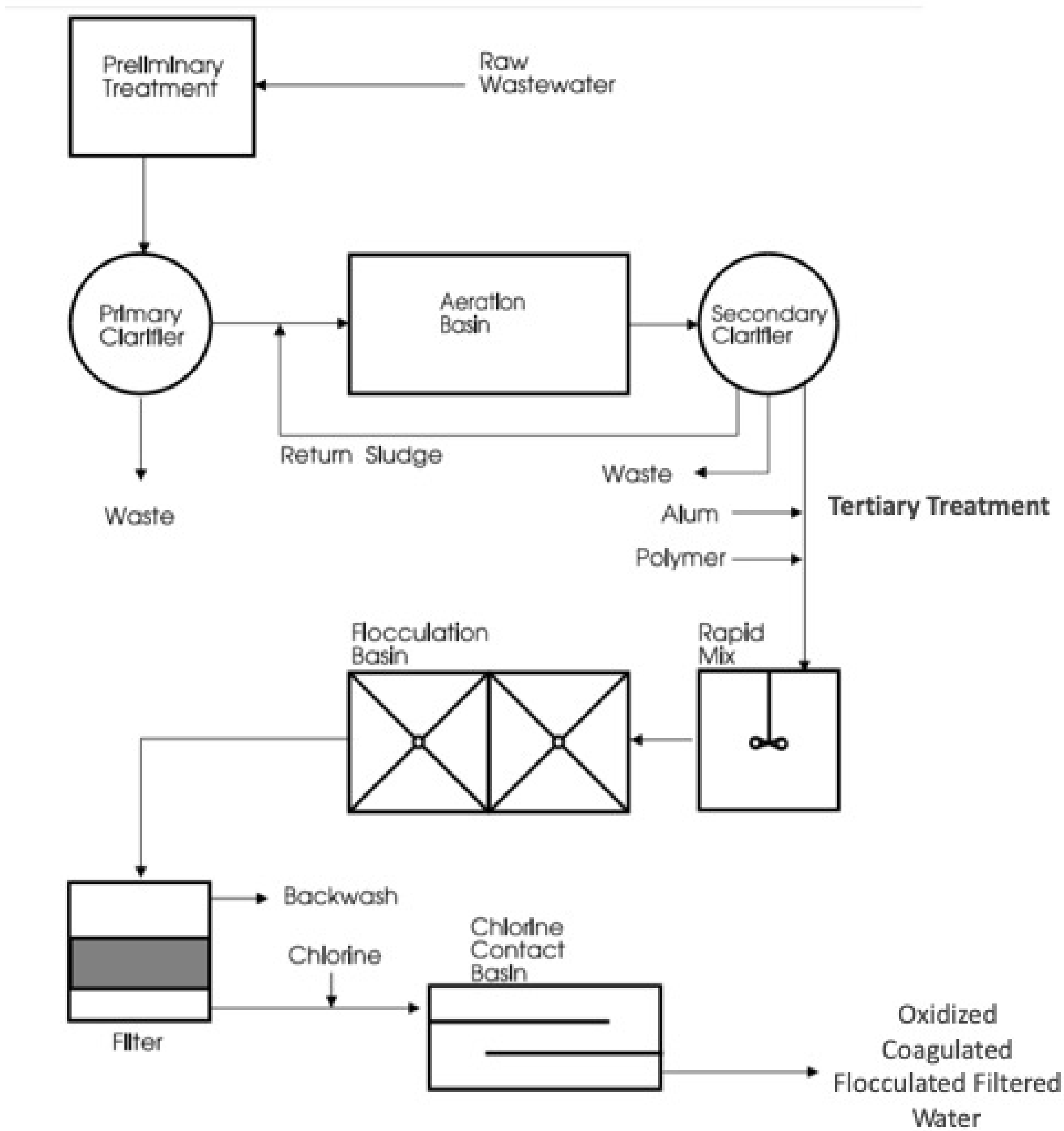

Figure 7: Schematic diagram of the treatment process at a wastewater treatment facility.

The suitability for reuse of reclaimed water is determined by quantitative physical, chemical, and biological characteristics. The requirement of contaminant removal for its further use is based on the level of treatment, specific concentration of a particular constituent must meet the given physical, chemical and biological standards defined by the regulatory agency. Typically, two levels of drinking water standards are defined for specific uses. In Virginia, for example, categorizes specific water quality as level 1 and level 2 (shown in Table 1). The state has set Corrective Action Thresholds which target the bacterial, turbidity and Total Residual Chlorine. The BOD (5 day) test to measure organics and is set as monthly limit. The level 2 water quality requires lower BOD. Level 2 sets BOD limit monthly average limit as < 10 mg/L while level 1 doesn't have any BOD 5 limit.

The level 2 treatment along with advanced disinfection of wastewater is required if the reclaimed water is used for irrigation of any property which is accessed by public, for example, agricultural fields (if food crops that is eaten raw) or golf course or school yards and parks. On the other hand, the level 1 treatment with standard disinfection is recommended for properties that are not accessible to public, for example, the reclaimed water after level 1 treatment can be used for the irrigation of nonfood crops, sod farms, or silviculture (Table 1). The recycled water should be of high-quality and strictly monitored for irrigation to avoid direct human contact or limit the exposure to recycled water at the time of irrigation.

Table 2: Summary of the contaminant removal according to the treatment standard. (Adapted from Haering et al., 2009)

		Level 1: Secondary treatment with filtration and higher-level disinfection	**Level 2: Secondary treatment with standard disinfection**
Bacterial Standards - (at least one of these three standards must be met)	Fecal coliforms	Monthly geometric mean[a] ≤ 14/100 mL CAT[b] > 49/100 mL	Monthly geometric mean ≤ 200/100mL CAT > 800/100 mL
Bacterial Standards - (at least one of these three standards must be met)	Enterococci	Monthly geometric mean ≤ 11/100 mL CAT > 35/100 mL	Monthly geometric mean ≤ 126/100mL CAT > 235/100 mL
Bacterial Standards - (at least one of these three standards must be met)	E. coli	Monthly geometric mean ≤ 11/100 mL CAT > 24/100 mL	Geometric mean ≤ 35/100mL CAT > 104/100 mL
Total Residual Chlorine (TRC)[c]		CAT < 1 mg/L after a minimum contact time of 30 minutes at average flow, or 20 minutes at peak flow	CAT < 1 mg/L after a minimum contact time of 30 minutes at average flow, or 20 minutes at peak flow
pH		6.0-9.0	6.0-9.0
5-day BOD (BOD_5)[d]		Monthly average ≤ 10 mg/L	Monthly average ≤ 30 mg/L Maximum weekly average = 45 mg/L

5-day Carbonaceous BOD ($CBOD_5$)[e]	Monthly average ≤ 8 mg/L	Monthly average ≤ 25 mg/L Maximum weekly average = 40 mg/L
Turbidity	Daily 24-hour average ≤ 2 NTU CAT > 5 NTU	N/A
TSS	N/A	Monthly average ≤ 30 mg/L Maximum weekly average = 45 mg/L
REUSE TYPE	**Food crops that are not commercially processed; any food that will be eaten raw Container nurseries Landscape irrigation, including Golf courses, Parks, Athletic fields, School yards, Cemeteries, Impoundments with public access**	**Food crops that are commercially processed, Nonfood crops, Pasture Ornamental nursery (non-container), Sod farms, Silviculture, Landscape impoundments with no potential public access**

5. Barriers to wastewater reuse

Reclaimed water has been used for decades and required structural pathways and policies were established. Nevertheless, the feasibility and sustainability of water reclamation and reuse remains elusive. The existing worldwide water reuse systems can be mainly categorized as centralized and decentralized systems. Decision making about urban water infrastructure projects is complex; the existing wastewater reuse system can be categorized as centralized or large-scale systems benefits from economies of scale in management and treatment costs but require significant investments in distribution systems to convey water for large distances. On the other hand, decentralized systems are implemented for smaller urban areas such as individual households, cluster of buildings or districts [24, 25]. In spite of the established structured system for wastewater reuse, there is inter-dependence between existing infrastructures, complex hydrologic, economic, environmental, financial, institutional, and social conditions, and water, land and energy use constraints. As a result, local constrains, including economic, political, environmental, social and technological factors determine what water reuse scheme is best for the implementation in different regions of the World [26, 27]. For example, the water demand in densely populated cities has led to the implementation of several centralized indirect potable reuse systems in California, where reclaimed water should meet the regulatory limits similar to standards for drinking water then it can be further used to recharge ground-water or mixed with surface water, and then utilized for potable purposes (California Department of Public Health, 2009). On the other hand, in Texas, the treated wastewater is directly added to the drinking water distribution network to augment potable water supply due to a cost reduction for a non-needed development of indirect potable reuse systems [25].

Furthermore, cost-effectiveness is one of the biggest obstacles for water reuse projects. About 35% of energy budget of U.S. municipalities is used for water and wastewater treatment facilities [23]. Because wastewater treatment plants (WWTPs) require high levels of energy (e.g., pumping, aeration) and resource consumption (e.g., chemicals) to transport and treat wastewater [21,22]. Other than the economics related issues, public support is an integral part of water reuse project success and at the same time public rejection act as a significant barrier to the implementation of water reuse schemes. Community involvement is critical for success of reclaimed water projects especially in projects where public requirements and perceptions dictate the design and/or where no viable alternative exist[6, 28]. Even though regulatory agencies and public are making significant efforts to deal with water shortages, new policies should be implemented that takes into account the factors including political, decisional, social, economic, and technological advances.

6. Concerns of using reclaimed water for irrigation

Even though reclaimed water has significant benefits, there are several concerns related to environmental and health risks. The primary concern of using recycled water for irrigation is increase in salinity including sodicity and bicarbonate hazards that may cause root zone salinization and ultimately leads to groundwater contamination [29]. Therefore, the use of recycled water for irrigation of food or non-food crops raises the concern for the public and environmental safety. Overall, the impact of recycled water characteristics on soil and public health is discuss below:

6.1 Soil health

Salinity problems due to irrigation using recycled water is compounded by effects of sodium (Na^+) on the dispersion of soil colloids, resulting in a loss of soil structure. However, salt accumulation is not common in humid areas, for example, Florida where abundant rainfall washes excess salts through sandy soil profile. Na^+ and Cl^- accumulation is a major problem in the coastal areas due to the influence of seawater, therefore, monitoring the salt levels is advised to check whether the recycled water is suitable for reuse. Salinity is determined by measuring the concentration of soluble salts in water that are quantified as Electrical conductivity (EC, units = dS/m) or total dissolved solids (TDS, units = 7 mg/L) concentration of the water. There are number of studies have been performed to observe the changes in salt concentration with the use of recycled water [30]. Although the salt accumulation is reported due to the use of recycled water for irrigation, there are other factors such as plant tolerance and soil characteristics play a very important role towards salinity increase. For example, irrigation with a high concentration of sodium (Na) ions may cause dispersion of soil aggregates and sealing of soil pores and ultimately affects the saturated hydraulic conductivity of soil. It is advisable to use reclaimed water depending on the plant tolerance and soil characteristics.

Furthermore, plants need low concentration of Boron (B) and chlorine for their development. The use of recycled water for irrigation may cause toxicity in plants. Even the low concentration (1-2 mg/L) of B can lead to leaf burn in the plants, however, some of the plants such as turfgrass can tolerate high concentration of B and chlorine [31]. Another issue with reclaimed water is heavy metals (cadmium, copper, molybdenum, nickel, and zinc), however, these metals are typically strongly bound to the solid fraction, or biosolids portion, of the wastewater and rarely are found in high enough concentrations to pose a reclaimed water quality problem.

The impact of recycled water on soil health is still debatable as the hydraulic conductivity has been observed to be decreased with the use of reclaimed water for irrigation [32, 33]. On the contrary, some investigators reported less or no effect of soil salinization due to recycled water application in open spaces [34]. However, the intensive monitoring for each parameter is recommended to avoid mass loading of salt and other components in soil [35].

6.2 Public Health

Microbial contamination is the biggest issue relating to recycled water irrigation. Microorganisms (pathogens, viruses, bacteria, protozoa and helminths) in recycled water may pose risk to human health when raw vegetables irrigated with recycled water are consumed [36]. Therefore, many researchers are studying the long-term impact on public health and there are several models available to assess the health risk from recycled water. Hamilton et al. (2006) used the Quantitative Microbial Risk Assessment (QMRA) to study annual risk of virus infection associated with the consumption of raw vegetables irrigated with recycled water [37]. However, this model has some disadvantages; it is tedious and technologically demanding. Hamilton et al. (2007) used another model Recycled water irrigation risk assessment (RIRA). This model calculates the annual risk of infection by using pathogen specific dose-response [38]. Donald et al. (2009) conducted a study to address microbial contamination from recycled water. The conceptual model involved recycled water and distribution pathways, exposure pathways and populations, cumulative end-user dose, identified toxicity and pathogenicity pathways, individual covariates and health endpoints [39]. Overall, the standard health risk assessment varies depending on several independent factors but it is still mandatory to ensure the reclaimed water quality by performing advanced treatment methods in order to meet the regulatory guidelines before it is used for irrigation.

7. Case Studies

7.1 Water Conserv II, FL (http://www.waterconservii.com)

Water Conserv II was born out of the need at City of Orlando and Orange County to expand the wastewater treatment capabilities and eliminate the discharge to surface waters. The project is an innovative largest reuse project, which combined agricultural irrigation and aquifer recharge via rapid infiltration basin (RIBs). The RIBs are rapid infiltration basin use the excess daily wastewater flows, and flows during wet weather periods. The RIBs consist of one to five cells, measuring about 350 feet long by 150 feet wide. They are built over a natural sand ridge with thickness of 30 to 200 feet. Below the surficial sands is a semi-permeable clay known as Hawthorn formation. The Hawthorn acts as a barrier separating shallow groundwater flow within the surficial sands from deeper, confined flow in the Floridan aquifer, which is comprised primarily of fractured limestones and dolomites.

The water conserve is permitted by FDEP (Florida Department of Environmental Protection) for use in irrigation of crops (human consumption). The FDEP standard for public access reuse and is permitted for use on all public access sites including residences and golf courses, food crops, foliage and landscape nurseries, tree farms, pasture land, the production of soil cement, and can also be used for fire protection. The reclaimed water is pumped city's Conserv II water facility to water conserve II distribution center. The water is then distributed to the consumers for irrigation or to RIBs. RIB process - the RIBs are built over a natural ridge sand that allows vertical flow downwards into the Floridian aquifer. The water quality meets the federal and state primary and secondary drinking water standards. The process is illustrated in the picture below in Fig. 8.

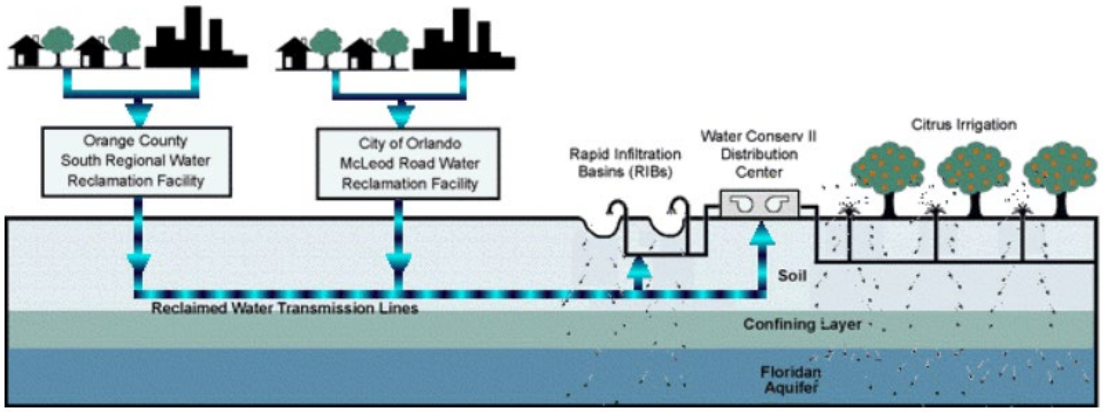

Fig. 8. Process of wastewater treatment process at Conserv II water facility.

7.2 Irvine Ranch Water District (IRWD), CA - Recycled water for landscape irrigation [31]

Irvine Ranch Water District (IRWD) was established in 1961 in the Orange County, California. In 2000, IRWD merged with the Los Alisos Water District and began serving customers with recycled water from the Los Alisos Water Reclamation Plant (WRP). The main objective of using the recycled water is to maximize drinking water supplies by reducing the need to use potable water for non-potable uses. IRWD has established recycled water distribution system for a 133 square mile service area with population of 316,000; includes two wastewater treatment facilities (Michelson and Los Alisos WRPs) to treat wastewater to tertiary standards (i.e., total coliforms ≤2.2/100 mL and turbidity ≤2 NTU) specified in the California Department of Health Services Water Recycling Criteria for high level non- potable uses, such as irrigation of residential property. Recycled water is delivered throughout the community through a dual distribution system that includes more than 300 miles of recycled water pipelines, 12 storage reservoirs, and 15 pump stations. Two of the reservoirs are open lakes; the others are pre-stressed concrete or steel tanks.

The recycled water is primarily used for landscape irrigation including parks, school grounds, golf courses, a cemetery, freeway landscapes, city-maintained streetscapes, common areas managed by homeowner associations, and front and back yards at individual residential dwellings, including large residential estate lots. Recycled water is also used for food crop irrigation, toilet and urinal flushing in 12 dual-plumbed office buildings, and in commercial office cooling towers.

About 20 percent of IRWD's total water supply is recycled water, reducing the need to import additional and expensive water from the Colorado River and Northern California. The Michelson WRP has a capacity of 15 mgd and the Los Alisos WRP has a capacity of 5.5 mgd. However, the IRWD service area is still developing which requires additional recycled water in the future. IRWD's plans to expand the Michelson WRP within its existing boundaries to eventually produce 33 mgd by 2025 and the Los Alisos plant to 7.8 mgd.

8. Conclusions

Wastewater is considered as a reliable and stable source of water for various purposes because its flows do not vary with seasons, climatic conditions, or precipitation levels, and therefore contributes considerably for use in irrigation thus significantly addressing the stress of global water deficit. However, it also leads to several issues in terms of human and environmental health if not treated or regulated properly. As a result, wastewater treatment has been evolving in past few decades in order to make it suitable for further reuse. Modern advances in reverse osmosis look promising. Recently, feasibility of an innovative integrated anaerobic membrane bioreactor (AnMBR)-reverse osmosis (RO)-ion exchange (IE) system was evaluated to produce reclaimed water with high energy efficiency and minimal waste sludge production (Gu et al., 2019). Hybrid forward osmosis and nanofiltration (FO-NF) system has been tested at pilot scale for wastewater reuse in agriculture irrigation [40]. Such technologies offer a new direction to wastewater treatment with reduced energy consumption and high operation sustainability. Another hybrid approach, integration of seawater desalination and advanced wastewater treatment facilities offers promising solution to produce high quality water to support potable water needs [41]. With this integrated approach, the amount of water available for potable and other uses is increased and effluent water from desalination and membrane type water treatment plant is of high quality, therefore, the combined flow is easier to treat and reclaimed water could be used locally, thus avoiding the need for environmental buffers (e.g., groundwater or surface water) and long pipelines to deliver dilution water [42].

Not only the treatment technology is critical factor but also economy and socio-politic considerations are vital subjects of research in the wastewater field. The concept of the Best Available Technology and the implementation of Decision Support Systems as well as approaches based on Risk Management should be considered to introduce water reuse for irrigation and potable purposes. To meet future water resource management and water reuse challenges effectively, cities must embrace the one water concept. Nonetheless, wastewater irrigation offers significant economic, societal, and ecological benefits towards water conservation.

9. References

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