# Chapter 6
# Wastewater Reuse in Peri-Urban Agriculture Ecosystem: Current Scenario, Consequences, and Control Measures

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## 6.1 Introduction

India is now the second most populated country in the world that sustains more than 16% of the world's population with only around 4% of the world's freshwater (The World Bank Group 2016). In India, the agriculture sector has been the largest consumer of water, although in next two decades share of water allocated to irrigation will be lowered to 10–15% (CWC 2000). Water is a vital natural resource that is an essential requirement for sustaining the life. It is investigated that 2.4 billion people in the world are unable to assess clean water, while 946 million of people are compelled to drink contaminated water and have unsafe sanitary practices (WHO 2014). The first evidence of wastewater reuse was found among the ancient Greeks, where flushed wastewater from public toilets was stored in several storage chambers through a sewerage line system (Jaramillo and Restrepo 2017).

Industrial or municipal wastewater reuse in agriculture is a common practice in suburban areas of developing countries (Urie 1986; Jeong et al. 2016; Jaramillo and Restrepo 2017), including India (Singh et al. 2004; Sharma et al. 2007; Kumar and Tortajada 2020). In this changing scenario, reutilization of domestic and industrial wastewater in agriculture for irrigating the plants such as crops, vegetables, etc., appears to be a valuable option. Besides being the source of irrigation, wastewater contains appreciable amounts of many plant nutrients such as macronutrients, micronutrients, organic matters, etc., but along with this it also contains harmful contents such as heavy metals and different emerging contaminants such as pharmaceuticals and personal care products, etc., which pose health risk to the living organisms (Kibuye et al. 2019). Heavy metals are more toxic due to its prevalence, non-biodegradable, and persistent nature.

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Overpopulation, industrialization, rapid urbanization, unplanned land use pattern, overexploitation of groundwater, chemical spills, storage tank leakage, unmanaged transportation, overuse, and surface runoff of agriculture fertilizers, etc., are the main cause of wastewater generation (Xia et al. 2017). Only one-tenth part of total generated sewage is treated and only one-third part of total urban household are connected to closed sewerage system (Sugam and Ghosh 2013). Most of the industries are not capable to treat wastewater due to their higher cost of operation and conventional chemicals. According to CPCB (2013), the total amount of sewage generation from 35 metropolitan cities (population one million and above) is 15,644 MLD and the treatment capacity is for 8040 MLD, i.e., only 51%.

Reuse of wastewater increased in the developed countries than developing countries due to the availability of more resources or facilities, e.g., in Europe and United States wastewater reuse increased 10–29% per year, and in Australia it increased up to 41% per year (Aziz and Farissi 2014).

For treatment of wastewater, types of sustainable infrastructure continuously increase by using several approaches such as physico-chemical approaches (sedimentation, chemical precipitation, adsorption, ion exchange, coagulation, catalytic removal, and nanotechnology) and biological or green approaches (different types of bioreactors, trickling filters and rotating biological contactor). By emphasizing these several techniques, we are expected to understand that how the wastewater is easily collected through drainage system, well treated, discharged, and reutilized. But unfortunately, in present time progress toward these several sustainable approaches is not well evenly distributed among all the nations (Rarasati et al. 2017).

There are several factors which affect the wastewater irrigation in agriculture field, e.g., chances of availability of freshwater or groundwater through tube well or canals for irrigation at affordable rates, consistency and reliability of wastewater generation through drainage system, level of nutrients in wastewater, acidity, alkalinity or salinity level of wastewater, contamination level of industrial effluents in wastewater, etc. Instead of freshwater irrigation, agriculture field irrigated by wastewater due to freshwater scarcity lead to food chain contamination, i.e., heavy metals transfer from soil to food plants (Fig. 6.1). Mobility of heavy metal depends upon its bioavailability in soil (present in different chemical forms) as well as its translocation and distribution varies by the species and population of plants (Liu et al. 2007; Sharma et al. 2020a).

Knowledge of the long-term impact of wastewater irrigation on metal or metalloid dynamics in soil-plant system should be improved for maximizing the benefits of wastewater irrigation as a viable source. Muchuweti et al. (2006) suggested drip irrigation method as a suitable and eco-friendly approach for mitigating the negative effect of wastewater irrigation on soil properties whereas flood irrigation in agriculture field badly affected the soil qualities. In present time, it becomes necessary to think about the existing urban wastewater disposal infrastructure, wastewater agriculture practices, quality of water consumed and its health implications, and the level of institutional awareness on wastewater-related issues (Rutkowski et al. 2007). By re-engineering the whole treatment plant structure, energy can be saved in wastewater treatment plants for increasing its reliability and efficiency. Combined heat

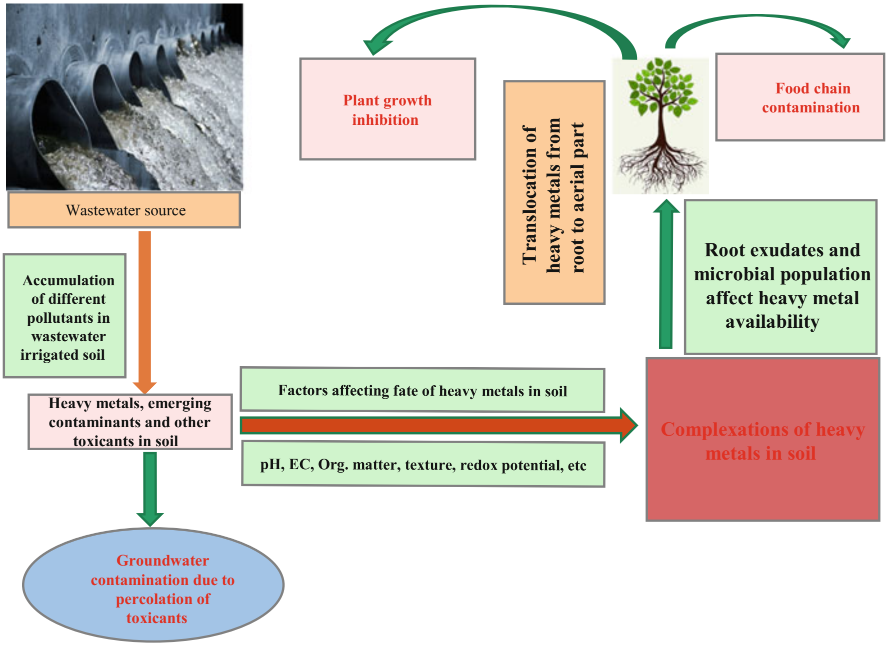


**Fig. 6.1** Threats to food chain due to wastewater irrigation in agriculture field. (Modified from Khalid et al. 2018)

and power techniques (CHP) play an important role as a source of energy, which use its own energy in the form of heat and electricity. Waste materials released from the treatment plant can be used for generation of biogas and energy using CHP techniques.

With the above context, the present chapter is concerned with the different aspects of wastewater reuse both at national and international level. The chapter further gives comprehensive accounts on the impact of wastewater irrigation on soil and groundwater quality which adversely affect food chain. Moreover, this chapter also proposes several control measures for wastewater treatment and management strategies to minimize the human health risks associated with the reuse of wastewater.

## 6.2 Current Scenario of Wastewater Reuse

Treatment of wastewater and its reuse is not a new concept. Several decades ago, untreated domestic wastewater was applied in agriculture but as time passes different technologies evolved and treatment of wastewater becomes possible. Present knowledge of wastewater treatment continued up to twentieth century in the USA, Australia, Europe, and other parts of the world without taking serious public health concerns and negative environmental impacts. However, in the present time these treatment systems are not commonly accepted due to their drawbacks like requirement of large area, problems in field operation, high cost, and difficult to achieve the higher hygiene standards (Tzanakakis et al. 2014).

### 6.2.1 International Scenario

Wastewater reuse for agricultural irrigation is more important in water-scarce countries. For irrigational purposes, quality and nature of wastewater reuse vary among different countries. Antwi-Agyei et al. (2016) interviewed 490 respondents of Accra, Ghana during two cropping seasons and found that awareness about the sources of wastewater in consumers and street food vendors was low as compared to market vendors. In terms of health risk awareness, it was generally low among the farmers and high among consumers and salespersons. This study promoted the intervention that directly benefits farmers, vendors, and consumers along with improvement in the knowledge of food safety and hygiene. Thebo et al. (2017) reported that at global level, approximately 11% of urban and peri-urban agriculture field area was irrigated with untreated wastewater. They concluded that the consumers, who depend on wastewater irrigated crops, must be assured for food safety by estimating the level of contaminants.

Moussaoui et al. (2017) reported that urban untreated wastewater is reused in agro-forestry sectors of Marrakesh city in a sustainable way. Local climatic condition of this city is an ultimate challenge for conserving the quality of wastewater resources, due to the degradation of organic matter, i.e., foul smell and availability of pathogenic microbes which had negative impact on soil quality in terms of fertility as well as its productivity. To face this problem treated wastewater irrigation becomes reliable and sustainable strategy, which enhanced soil fertility and combating water scarcity. Rezapour et al. (2019) studied Cd accumulation in wheat grain cultivated in the wastewater irrigated agriculture field of Western Azerbaijan Province, north-western Iran. The accumulation of Cd and its translocation and carcinogenic health risk were estimated through food chain contamination that ultimately affect the human life. Cadmium (Cd) is non-biodegradable and highly persistent in nature. Translocation factor for Cd through root to grain ranged from 0.18–0.24 and its carcinogenic health risk was found to be low to moderate risk category (Rezapour et al. 2019). Wastewater irrigation from outlet of electroplating factory threatened the agriculture quality (Xiao et al. 2019). Soil pH as well as concentrations of total and secondary phase fraction, i.e., bioavailable fraction (acid-soluble, reducible, oxidizable, and residual fraction) of heavy metals lowered down as the distance increased from electroplating factories. Redundancy analysis and stepwise regression analysis showed that soil pH, silt content, amorphous Fe oxides, and Mn oxides affected the Secondary Phase Fraction. Concentration of heavy metal concentration in soil and varied up to 68.8% and 43.5%, respectively.

### 6.2.2 National Scenario

Wastewater reuse for irrigation in Indian agriculture field is in practice from several decades. The treated or untreated forms of wastewater are widely used for irrigation in urban and peri-urban areas. Although there are no certain comprehensive data for total wastewater used for irrigating agriculture lands, some studies reported its considerable use. One of the studies from the International Water Management Institute by Amerasinghe et al. (2013) has reported that about 50,000 ha land was irrigated by urban wastewater. In peri-urban areas, a variety of crops were grown under wastewater irrigation, most commonly being vegetables for local urban markets. Vegetables are important dietary constituents of human food, which fulfil various needs of nutritional components. Sharma et al. (2007) found that farmers of suburban areas of Varanasi irrigated their vegetables like palak (*Beta vulgaris* L. var. All green H1) with wastewater. This vegetable was grown due to its short growth period, number of harvested times in single cropping, required low agriculture area, low labor cost, etc. Analyses of heavy metal in irrigational water, soil and vegetables in both summer and winter seasons had shown that concentrations of Cu, Zn, Pb, Cr, Mn, and Ni in irrigational water and soil were below the recommended limit, except Cd which was higher in winter than summer. However, in edible part of palak Cd concentration was higher during summer; but, Pb and Ni contamination were higher in both the seasons.

Municipalities at Bhavnagar, Rajkot, Gujarat put some charges for irrigating the agricultural lands with wastewater like municipal corporation of Bhavnagar and Rajkot charges Rs. 750/ha and Rs. 2500–3000/ha, respectively (Palrecha et al. 2012). Farmers of peri-urban area of Hyderabad use wastewater for irrigation and prefer to pay charges which help the industries to treat their wastewater and this information is also valuable for planning small on-site wastewater treatment systems which help in improving livelihood in risky environment (Saldías et al. 2017).

Sahay et al. (2019) analyzed the effect of wastewater irrigation on growth, physiological characteristics, and productivity of different *Brassica* species. In this experiment, wastewater irrigation was done along with the amendment of NPK at two different doses ($N_{60}$ $P_{30}$ $K_{30}$ and $N_{80}$ $P_{45}$ $K_{45}$). The amendment of NPK with 80:45:45 did not show significant effect; however with 60:30:30 dose, the crop showed more production due to the reduction of Ni, Cd, Cr, Pb, and Cu accumulation in plant parts. Radhika and Kulkarni (2019) studied in Hubli-Dharwad, twin cities (Karnataka), second largest populated city after Bangalore, where sewage flow rate rapidly increased by 12 times with 1.07% per annum growth rate. This trend of sewage flow with growth rate creates a challenging task for government to manage sanitation problem and its utilization.

Heavy metals content in soil from Dankaur and Kasna villages, Greater Noida, UP (India) irrigated with treated wastewater released from 137 MLD sewage treatment plant was analyzed by Hussain et al. (2019). A pot experiment performed by Sharma and Agrawal (2006) has reported that the vegetables such as spinach (*Spinacea oleracea*), radish (*Raphanus sativus*), and carrot (*Daucus carota* Sub sp. *sativus*) showed more accumulation of Cd, Cu, Zn, Co, and Mn in their leaves. Treated wastewater irrigated soil showed variations in enrichment factors with decreasing trend like Zn > Ni > Pb > Cr > Cu > Co > Mn > Cd (Hussain et al. 2019).

## 6.3 Composition of Wastewater

On the basis of sources, wastewater can be categorized into three types, i.e., (i) storm runoff, mainly natural causes, (ii) industrial wastewater, released through several industries, and (iii) domestic wastewater, released through households. Domestic wastewater is categorized into two parts: (i) black wastewater and (ii) grey wastewater. Black wastewater contains higher amount of organic materials than the greywater. Storm runoff water dilutes the wastewater and diluted wastewater has also higher concentrations of organic material than storm runoff water. Detailed classification of wastewater is given in Fig. 6.2.

Concentration of wastewater can be estimated by the addition of pollution load in a particular amount of water or vice versa. Pollution load analysis on a daily, monthly, or yearly basis is a good indicator of the composition of wastewater. Composition of wastewater is influenced by both the location and time as all places do not have similar types of pollution sources, i.e., either domestic or industrial sources (Mohan et al. 2014). Seasonal variation in wastewater contaminants is also ascribed to dilution process, e.g., in rainy season more dilution of wastewater leads to lower concentration of contaminants. Wastewater contains different types of contaminants such as different chemical compounds (inorganic, organic, and different emerging contaminants) and harmful microbial populations.

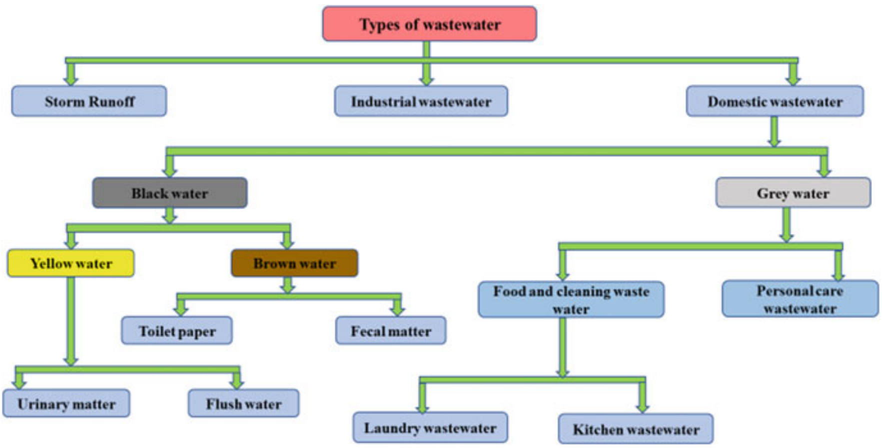


**Fig. 6.2** Classification of wastewater. (Modified from Boutin and Eme 2016)

## *6.3.1 Chemical Compounds in Wastewater*

### 6.3.1.1 Inorganic and Organic Chemicals

In wastewater, different types of inorganic constituents occur such as heavy metals, different salts, oxyhalides (bromate, chlorate, and perchlorate), and types of nanomaterials whose concentration depends upon their source and degree of treatments received. National (Bureau of Indian Standard) and International agencies (FAO/WHO) set guidelines for industrial discharge of wastewater to reduce health risk. These guidelines set limit for the standards for metals and metalloids in the sewage discharge. Heavy metals and oxyhalides are bioaccumulative in nature and highly persistent in nature. Due to long-term wastewater irrigation in agriculture field, the contaminants get rapidly accumulated in soil and cause an adverse effect on living organisms through food chain contamination. Macronutrients such as nitrogen and phosphorous also present in excess amount in wastewater stream. These excess occurrences of macronutrients cause eutrophication in water body due to more algal growth.

Sources of organic components in wastewater include household wastes (liquid waste, humic substances, fecal materials through toilets), types of industrial waste, fats, greases, and oils, etc. Wastewater irrigation of soil is low-cost resource of macronutrients and organic matter content. These strategies can be successfully applied in restoration of degraded croplands, eroded soil in hilly areas, or arid and semi-arid areas (Chatzistathis and Koutsos 2017). Organic materials act as a source of carbon for microbial growth and also sometimes lead to clogging which promote growth of microorganism in wastewater. In wastewater treatment process, secondary treatment is done for organic matter removal through microbial population. Organic materials present in the wastewater are beneficial for agricultural purpose as it contain not only organic carbon but also macronutrients, which help in enhancing the fertility of irrigated soil.

### 6.3.1.2 Emerging Contaminants

The emerging contaminants (EC) are newly identified compounds, organic in nature, and released into the environment by anthropogenic activities (Yankui et al. 2019). The pharmaceutical companies of personal care products, pesticides synthesizer, household chemicals, transformation products, etc., are mostly responsible for their generation. ECs include different natural or synthetic hormones, pharmaceutical products, endocrine disrupting compounds, artificial sweetener, etc. These contaminants are new in the origin, have alternate route to human exposure. A sequence of biological treatment coupled with advanced tertiary treatment such as activated carbon adsorption or chemical oxidation is used to remove such trace chemicals from wastewater.

Tran et al. (2019) reported 31 ECs in untreated wastewater, treated wastewater, urban storm runoff, agricultural runoff, and in freshwater which frequently influence the quality of urban surface water. For identifying and characterizing the origin of diffuse source in urban wastewater, selected ECs are developed as a marker. Twenty-one target ECs were detected 100% in the collected raw wastewater, samples with median concentrations ranging from 49.6 to 77,721 ng/L, while only 13 compounds were found with detection frequency $> 50\%$ in freshwater bodies. The median concentration of the majority of detected ECs was below 100 ng/L in freshwater samples. Thus, analysis of ECs such as acesulfame, acetaminophen, cyclamate, and saccharine may serve as a suitable marker of diffuse source in surface water.

## 6.4 Impacts of Wastewater on Natural Ecosystem

Water is necessary for survival of living organisms as it is susceptible in quality and limited in quantity or availability (Khan et al. 2018). Due to the increasing demand of freshwater or potable water for different purposes in different sectors like agriculture, industries, domestic, etc., threaten its sustainable use. Wastewater irrigation appears to be a good alternative source to enhance the availability of potable water for various purposes. However, wastewater also contains several chemical toxicants and harmful microbes. Long-term uses of untreated or treated wastewater in agriculture field considerably enhance the potential toxic metal content in soil and growing plants. These toxicants may further threaten food chain because of several human health hazardous effects (Dogan et al. 2014). Suitable strategies for proper foretelling of heavy metal uptake by food crops will help in appropriate risk assessment of wastewater irrigated soils. Soil, groundwater, or surface water and growing plants are impacted by long-term wastewater irrigation which is summarized as below.

### *6.4.1 Soil Characteristics*

#### 6.4.1.1 pH and Electrical Conductivity

Wastewater irrigation affects the physicochemical properties of soil such as pH, electrical conductivity, soil temperature, organic matter, cation exchange capacity, bulk density, soil porosity, soil hydraulic conductivity, and infiltration rate. Several studies have shown that soil pH lowered down by wastewater irrigation due to oxidation of participating cations (Khalid et al. 2018). Solubility of heavy metals increases at lower pH and causes an increase in heavy metal bioavailability in the soil which can be easily taken up by the growing plants (Zhao et al. 2015). Net negative charge, i.e., cation exchange capacity increases at higher pH and positive charge, i.e., anion exchange capacity increases at lower pH. Adsorption of metals is also affected by soil pH due to the change in surface charge (Bhargava et al. 2012). Electrical conductivity of soil increases more due to wastewater irrigation than groundwater irrigation. Ashraf et al. (2013) reported that electrical conductivity of wastewater reduced the yield of tomato by enhancing the salinity of soil.

#### 6.4.1.2 Soil Organic Matter

Organic matter is the major component to maintain the productivity of soil. The organic matter content in soil increases due to wastewater irrigation that enhanced the fertility of soil. Organic matter in soil is mainly in the form of humic substances or humus and non-humic substances. Major components of humus are humic acids and fulvic acids. At lower pH, high molecular weight organic acid, i.e., humic acids are not soluble in the soil solution and removed via precipitation. In case of fulvic acids, a low molecular weight organic acid is easily soluble at all pH and has more active sites than humic acid (Gupta et al. 2019a).

#### 6.4.1.3 Soil Temperature and Redox Potential

Temperatures of soil play an important role in the mobility and availability of metals in the soil and also affect the soil microbial health which helps in regulation of soil fertility. Soil temperature may be elevated through wastewater irrigation due to decomposition of soil organic matter which increases the availability of metals in soil. Cornu et al. (2016) reported that transfer of Cd and Zn from soil to plant increases at high soil temperature. Several metals are present in soil solution in oxidized forms or reduced forms and their mobility depends on its redox state, i.e., acceptance or removal of electrons from soil solution determined by its redox potential (Sheoran et al. 2016; Khalid et al. 2018).

#### 6.4.1.4 Some Other Characteristics

Soil bulk density is determined by the mass of undisturbed soil per unit volume and is represented as g $cm^{-3}$. Soil bulk density is always lower than the particle density due to occurrence of pore space. If, the bulk density of soil increases its porosity always decreases. Long-term wastewater irrigation changes the soil bulk density and porosity which depends on the quality of wastewater, i.e., concentrations of dissolved and particulate constituents in the wastewater. Shariot-Ullah (2019) studied that the effluents from the North Bengal Sugar Mill in Bangladesh affected agriculture soil properties, e.g., bulk density reduced from 1.44 to 1.42 g/$cm^3$ and porosity of soil increased approximately 2.17%.

The hydraulic conductivity and infiltration rate of soil is altered by wastewater irrigation. The factors such as types of soil, clay content, $CaCO_3$ amount, soil humidity, and types of wastewater are responsible for the alteration of hydraulic conductivity and infiltration rate of soil (Lado et al. 2005). Infiltration rate of wastewater irrigated soil is mainly affected by duration of the wastewater irrigation. Gharaibeh et al. (2007) observed that wastewater irrigation of soil up to 5 years significantly lowered down the infiltration rate, although irrigation period extends to 15 years, increased the infiltration rate due to the large cracks formation.

### *6.4.2 Water Resources*

The long-term wastewater irrigation not only affect the soil properties, i.e., alkalinity, salinity, nitrates, presence of potential contaminants, pathogenic threats, etc., but also lead to deterioration of groundwater quality due to the presence of excess salt, nitrates, and other toxic pollutants. Groundwater shares the largest portion of freshwater on earth, which is continuously overexploited by the various anthropogenic activities such as agriculture, industries, and also in domestic sectors, etc. Any substance which is soluble in nature, easily penetrate to groundwater and deteriorate its quality, e.g., wastewater contain water-soluble complexes with organic ligands which are easily leached down into different soil layer and ultimately mixed with the groundwater. Freshwater resources like surface water vary with different climatic conditions but groundwater is not directly affected by such conditions. Groundwater contamination is increasing day to day, unfortunately it is contaminated with several potential toxic pollutants which become extremely dangerous for the living stocks. Treatment of groundwater is very costly because it requires expensive operation systems or other facilities. According to Agrawal et al. (2016), there is an urgent need for consistent monitoring of the risk assessment and proper management of groundwater to reduce the pollutant loads.

Madhav et al. (2018) reported the groundwater pollution in Bhadohi district of Uttar Pradesh due to massive industrialization of carpet sectors, 40% groundwater samples of this area have nitrate content above the permissible limit (>50 mg/l), which cause harmful effect on human health, especially in children cause methemoglobinemia (blue baby syndrome) which leads to create hypoxic condition. Gupta et al. (2019b) studied different villages area of Jajmau, Kanpur, Uttar Pradesh to assess the groundwater quality which is badly affected by rapid industrialization. Kanpur city is hub of various industries mainly for tannery industries, approximately more than 800 in number. Industrial discharge containing different types of contaminants caused serious health problems to local people. These contaminants not only affect the surface water but groundwater also gets contaminated due to leaching processes. Results of this study showed that groundwater contains higher amounts of TDS ranged between 2835 mg/l – 2581 mg/l, and heavy metal, mainly chromium concentration (0.004–0.13 mg/l), exceeded its permissible limit. Cr is carcinogenic in nature and also its hexavalent form is more dangerous than the trivalent form.

### *6.4.3 Food Chain Contamination*

Wastewater irrigation affects human health in both aspects either positively or negatively. Positive aspect of wastewater irrigation is related to food security of the water-scarce zone and negative aspect of wastewater is based upon the presence of different toxic potential contaminants and pathogens, etc., above their permissible limits. Among all the wastewater irrigated food plants, vegetables are the major food crops, consumed at a global level. Vegetables accumulated the toxicants in their edible parts. Approximately 90% of total metals enter to the human body via intake by vegetables and other edible crops as it is the major component of the human diet and the remaining 10% metal through inhalation of dust and dermal contacts (Martorell et al. 2011; Khan et al. 2014; Gupta et al. 2019a). Heavy metals negatively affect the nutritional value of the foods. The plants irrigated with wastewater were found nutrient deficient due to antagonistic interaction between metal and nutrient such as Cd suppress the uptake of Zn due to same carrier transporter protein (Salgare and Acharekar 1992; Sharma and Agrawal 2006).

For security of human health and food safety, it is important to characterize the sources and concentration of heavy metals in wastewater, irrigated soil, and growing plants in order to establish quality standards (Sun et al. 2013). Because of higher demands of food in the recent decades, food safety has become one of the burning issues with respect to human health. This context provokes researchers and scientist to work on food chain contamination by heavy metals and its associated health risks. The concentration of heavy metal (mg/kg) in wheat grain irrigated with wastewater varied between 0.1–0.9, 0.3–0.5, 0.7–1.4, 0.8–1.6, 0.6–0.9, 1.2–1.6, and 0.06–0.2 for Zn, Cr, Cu, Mn, Ni, Cd, and Pb, respectively. Cd concentration exceeded permissible limit (0.2 mg/kg) set by FAO/WHO. Similarly, vegetables and other crops as well as milk produced under wastewater irrigation regimes were also found contaminated with potentially toxic heavy metals (Sharma et al. 2007; Gupta et al. 2019a).

## 6.5 Control Measures for Wastewater Reuse

Due to the rapid growth in industrialization, the level of contaminants is increasing day by day in industrial discharge, so, for healthy and safe environment their removal from wastewater is very important. Generally, conventional wastewater treatment approach is the combined form of different physical, chemical, and biological processes for the removal of contaminants including different hazardous metals, organic materials, colloids, and types of emerging contaminants from wastewater. Each treatment process has its own advantages and disadvantages in terms of cost, labor requirement, efficiency, reliability, practicability, feasibility, ecofriendly nature, operation process, energy cost, and quality of byproducts, etc. Treatment approaches also depend on the source and types of wastewater. Various physical and chemical processes applied for the removal of contaminants suffer from several limitations due to higher cost, energy requirements, basic properties alteration, and its residual byproducts (Crini and Lichtfouse 2019). For resolving such challenges, several types of green and sustainable approaches are developed by perceiving them as an ecofriendly approach. These techniques require less energy cost-effective, reliable, efficient, and highly accepted by the public. The different kinds of approaches used for removing the contaminants from wastewater are discussed as below:

## *6.5.1 Physicochemical Approach*

Researchers are using different types of the physicochemical methods such as gravity sedimentation process, coagulation, ion exchange, chemical precipitation, adsorption through abiotic materials, catalytic removal and nanotechnology, etc., to remove the toxic pollutants from the wastewater since many years.

### 6.5.1.1 Gravity Sedimentation Process

Sedimentation is a physical wastewater treatment process as well as also a part of primary wastewater treatment process, in which gravity plays an important role in the removal of suspended solids from the wastewater. Settlement ponds are used for the removal of higher weight suspended particles from wastewater with the help of sedimentation process. Clarifiers are built with mechanical means for consistent removal of suspended solids from the wastewater. In sedimentation process, removal of suspended solids is affected by its size and specific gravity (Demirbas et al. 2017).

### 6.5.1.2 Coagulation

In wastewater treatment, suspended materials of wastewater can be removed simply through settling process, but for the removal of smaller particles especially for colloidal particles, coagulation process plays an important role. Coagulation is a chemical process and it is achieved through the use of different coagulants, e.g., aluminum chloride ($AlCl_3.6H_2O$), sodium aluminates ($NaAlO_2$), alum, ferrous sulfate, etc. Due to the use of coagulants, aggregation of destabilize particles, and sedimentation substances form a larger particle called “Floc” and the process is called flocculation. The advantage of these flocs due to higher weight can easily be removed by sedimentation and filtration (Ebeling et al. 2003). Farhan (2019) analyzed the efficiency of different coagulants such as alum, ferrous sulfate and ferric chloride, etc., with the addition of different organic coagulants, e.g., polyethylene glycol, polyacrylamide, and inorganic, e.g., bentonite for removing higher and lower turbidity of the wastewater. Optimal dose of coagulants is also determined for higher removal of suspended solids and leaves less turbidity. Removal capacity of turbidity from the wastewater by alum, ferrous sulfate, ferric chloride, and calcium oxides was found to be 99.59%, 98.26%, 98.66%, and 92.18%, respectively (Farhan 2019).

#### 6.5.1.3 Ion Exchange

Ion exchange process is a physical approach for removing heavy metals from the wastewater. In this process, ions are reversibly interchanged between the solid, i.e., natural or synthetic solid resin and liquid phase. Resins uptake ions from electrolytic solution and release ions which are similar in charge or chemically equivalent (Cavaco et al. 2007).

#### 6.5.1.4 Through Adsorption Process

Adsorption process is a widely accepted physicochemical technique. It is based on the exchange of mass between liquid phase, i.e., wastewater and solid phase, i.e., adsorbent. Adsorption process is completed in several steps, first of all, contaminants move from wastewater to the surface of adsorbent, in the second step contaminants lock or adsorbed on adsorbent surface, and in the final step penetration of contaminants to the adsorbent structure. Adsorption process has been done in both, natural byproducts, e.g., rubber, cotton, rice husk, jute fiber, etc., and synthetic byproducts, e.g., zeolite, activated carbon, fly ash, iron slag, etc. (Salam et al. 2011). Huang et al. (2018) reported the removal of heavy metal (Pb, Cu, etc.) from wastewater through two types of zeolite, i.e., ZIF-8 and ZIF-67. ZIF-8 synthesized by addition of 2-methylimidazole and zinc nitrate hexahydrate ($Zn\ (NO_3)_2{\cdot}6H_2O$) in solvent of N, N-dimethylformamide (DMF). ZIF-67 synthesized by addition of 2-methylimidazole and cobalt nitrate hexahydrate ($Co(NO_3)_2{\cdot}6H_2O$) in a DMF solvent. Zeolite is highly porous material, which helps in improving the adsorption capacity. Adsorption capacity of ZIF-8 and ZIF-67 was 1119.80 and 1348.42 mg/g for Pb, and 454.72 and 617.51 mg/g for Cu, respectively. Adsorption capacity of such types of zeolite was very higher, take few minutes to reach adsorption equilibrium. These characteristics proved that ZIF-8 and ZIF-67 have good adsorption capacity for the removal of heavy metals from wastewater (Huang et al. 2018). De Abreu Domingos and da Fonseca (2018) performed a comparative study for the treatment of petroleum refinery wastewater by an adsorption process using activated carbon and ion exchange process through resins (styrene–divinylbenzene). The study verified the feasibility and reliability of both the processes and showed that the removal of contaminants from petroleum refinery wastewater through adsorption by activated carbon was 55% higher than the ion exchange process.

#### 6.5.1.5 Catalytic Removal

Now a day's catalytic removal of toxicants from the wastewater is a promising technology. Removal of non-biodegradable contaminants from the wastewater is achieved in presence of a catalyst through process of oxidation, rate of enhanced degradation. In the wastewater treatment process, oxidation of dissolved organic carbon in liquid phase is achieved in the presence of catalysts at lower temperature and pressure. Catalysts should be cost-effective, reliable, feasible, and have numerous active sites in its surface for improving its remediation capacity (Levec and Pintar 2007). For catalytic activity, noble metals, e.g., platinum, ruthenium, rhodium, palladium, etc., are used for abatement of contaminants from wastewater. Catalyst activities also depend on several factors such as wastewater pH, types and quality of wastewater, concentration of contaminants, etc. In corrosive environment, catalysts should be stable and mechanically strong after several run for higher oxidation and complete mineralization of organic components (Matatov-Meytal and Sheintuch 1998; Monteoliva et al. 2020). Yin and Zhu (2019) suggested use of solar energy in photocatalytic oxidation technology for the treatment of the wastewater from printing and dyeing chemical industries. Wastewater became more hazardous due to the presence of methylene blue dye effluents. For degradation of methylene blue dye effluents, a highly effective catalysts, $Ag^+$ nodes with 1,3,5-trimesic acid linker by the process of hydrothermal reaction were constructed. During the process of photocatalytic degradation, $Ag^+$ oxidized and become $Ag^{2+}$ and degradation mechanism completed in multistep phenomenon. At pH 3 and 20 min contact time, $Ag^+$ catalyst photocatalytically degrade 99.8% methylene blue of wastewater from the printing and dying chemical industries.

#### 6.5.1.6 Use of Nanotechnology

The availability of clean and affordable water for human need is a great challenge during the present time. Therefore, there is need of some innovational technologies for wastewater treatment. Nanotechnologies provide good potential for removing the toxicants from the wastewater and create an opportunity for advanced wastewater treatment technology. There are several properties of nanomaterials which improve its contaminants removal capacity such as large surface area, strong sorption capacity, higher fast dissolution rate, highly reactive, super magnetism, etc. There are some limitations of nanotechnology, e.g., higher cost, high quality of nanomaterials, technical proficiency, etc. Collaboration between industries, research centers, government, etc., is needed for avoiding these challenges and to improve the efficiency, reliability, and feasibility of nanotechnology (Qu et al. 2013). Hassan and Mahmood (2019) analyzed the efficiency of iron oxide ($Fe_2O_3$) nanoparticles for abatement of cadmium from sewage water of Medical City, Baghdad. The best conditions for maximum Cd removal, i.e., 96.9% are at pH 5.5, for 95.8 min contact time and with 20.77 mg/L of iron oxide nanoparticles (Hassan and Mahmood 2019).

## 6.5.2 Biological Approaches

Physicochemical approaches have certain drawbacks like higher cost, high energy input, changes in water quality, and disturbance in native flora communities. Therefore, recently biological or green approaches come into practices that are cost-effective, require less energy, more reliable, feasible, and eco-friendly. In this, different microorganisms such as bacteria, fungus, algae, etc., are used to degrade wastewater contaminants. Microorganisms are used in different engineering set up such as trickling filter, activated sludge process, membrane bioreactors, rotating biological contactors, etc., for wastewater treatment. Several sustainable and green approaches used for wastewater treatment are given in Table 6.1 and discussed as below.

### 6.5.2.1 Bacterial Biodegradation

In wastewater treatment technology, the use of bacterial community in different engineered systems such as trickling filter, rotating biological contactor, activated sludge process, etc., or as a biosorbent is highly considerable. The metabolic rate of bacteria determines its effectiveness in wastewater treatment. Microbial communities rich in species degrade a wider range of substrates than its pure culture. Biosynthesis of extra cellular polymeric substances by microbial aggregates through generated by cell lysis, secretion, released materials from cell surfaces are necessary for maintaining biomass structure and protects bacterial cells against various contaminants. Biological wastewater treatment system has been designed by considering three aspects, such as engineering, ecological, and microbial. With design and operation of wastewater treatment plants, integration of theoretical ecology allow better prediction of microbial population, variations in communities structure and function with changes in environmental conditions (Cydzik-Kwiatkowska and Zielińska 2016). Investigation of microbial communities is important for degradation of wastewater released from pharmaceutical, petroleum refineries, textiles, paper pulp industries, etc. (Ma et al. 2015).

Ajaz et al. (2019) reported that *Alcaligenes aquatilis* was used to decolorize 82% synazol red 6HBN from wastewater at pH 7 after incubation of 4 days at 37 °C. Under static conditions, maximum decolorization of wastewater by *A. aquatilis* was achieved in the presence of sawdust and yeast extract as a source of carbon and nitrogen, respectively. Results further showed that the maximum wastewater decolorization, i.e., approximately 86% of multiple dyes was found in 5 days incubation. *A. aquatilis* not only potentially decolorize wastewater but also transformed azo dyes into different useful end products applied in the environmental biotechnology.

**Table 6.1** List of sustainable and green approaches for removal of contaminants from wastewater

| S. N. | Sustainable process | Description | References |
|---|---|---|---|
| 1. | Application of aerobic upflow submerged attached growth reactor | Clear away ammonia, thiocyanate, and cyanate from gold mine wastewater | Di Biase et al. (2020) |
| 2. | Application of zooplankton (*Daphnia* sp.)-based reactor | Removed organic matter and heavy metal Cu from wastewater | Pous et al. (2020) |
| 3. | Use of microalgal consortia for treatment of municipal wastewater | Removed organic carbon and Cu, Cr, Pb, and Cd from sewage wastewater | Sharma et al. (2020b) |
| 4. | Use of Enhanced Biological Phosphorus Removal (EBPR) | Chemical precipitation with evidence of phosphate accumulating bacterial population | Meza et al. (2020) |
| 5. | Use of microbial community structure | Removed COD, terephthalic acid, para-toluic acid, benzoic acid, and acetic acid from wastewater | Ma et al. (2020) |
| 6. | Application of biological aerated filter | Removed ammonia, nitrate and phosphorus from wastewater | Li et al. (2020) |
| 7. | Use of aerobic granular sludge reactor | Clear away naphthalene, acenaphthylene, and acenaphthene from wastewater | Ofman et al. (2020) |
| 8. | Fenton's treatment followed by subsequent biological treatment | Reduced BOD and COD of pharmaceuticals wastewater | Changotra et al. (2019) |
| 9. | Integrated bio-oxidation and adsorptive filtration reactor | Removed arsenic from different industrial effluents | Kamde et al. (2019) |
| 10. | Integrated biofilter, i.e., biofilm, clam (*Tegillarca granosa*), and macrophytes (*Spartina anglica*) | Bio-filters significantly influenced the biodegradability and resolvability of particulate organic matter and control dissolve oxygen, water temperature, and nitrogen | Lukwambe et al. (2019) |
| 11. | Use of hybrid membrane photobioreactor and membrane photobioreactor | Removed atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) and CNP from wastewater | Derakhshan et al. (2019) |
| 12. | Use of indigenous microalgae (*Dictyosphaerium* sp. strain MM-IR2) | Improved sulfate removal from the power plant wastewater | Mohammadi et al. (2019) |
| 13. | Application of rotating biological contactors | Abatement of pharmaceuticals and personal care products contaminants from domestic wastewater | Delgado et al. (2019) |
| 14. | Biodegradation through halophilic *Halomonas* strain Gb bacterium | Toluidine red biodegradation in a synthetic wastewater | Amini et al. (2019) |
| 15. | Used filamentous microalgae *Tribonema* sp. culture | Removed COD, total N, total P and organic contaminants from petrochemical wastewater | Huo et al. (2019) |
| 16. | Use of moving biological bed reactors (MBBR) and sequencing batch reactors (SBR) | Shortening the level of COD, BOD, ammonium, and phosphate ion from fish processing wastewater | Nowak et al. (2019) |

(continued)

**Table 6.1** (continued)

| S. N. | Sustainable process | Description | References |
|---|---|---|---|
| 17. | Use of bioaugmented multistage biofilter | Deactivation of pathogenic micro-organisms from municipal wastewater | Ibrahim et al. (2020) |
| 18. | Application of aerobic and anaerobic membrane bioreactors | Abatement of 15 trace organic contaminants from synthetic wastewater | Liu et al. (2020) |
| 19. | Application of anaerobic moving bed biofilm reactors | Removed BOD and COD from oil-contaminated wastewater | Morgan-Sagastume et al. (2019) |
| 20. | Biofilm-membrane bioreactor (BF-MBR) | Use of biomarkers in *Mytilus galloprovincialis* in an integrated bioremediation approach for remediation of oily wastewater | Pirrone et al. (2018) |
| 21. | Use of biofilm | Removed hydrocarbons from polluted industrial wastewater | Rodríguez-Calvo et al. (2018) |
| 22. | Use of cocoa pod husks | Removed Congo red (CR) dye from industrial effluents | Olakunle et al. (2018) |
| 23. | Use of *Marsileaq uadrifolia* as a bioremediating agent | Removed BOD, COD, soluble phosphorous, total N, and heavy metal Zn | Abbasi et al. (2018) |
| 24. | Application of trickling biofilter (TBF) system | Reduction of BOD, COD, TDS, EC, phosphate, sulfate, and total nitrogen from domestic wastewater | Rasool et al. (2018) |

#### 6.5.2.2 Fungal Biodegradation

The fungal communities play an important role as a biological agent in degradation of toxicants from wastewater. Fungi can grow at a higher rate, produce much tolerant spores, enzymes, and have capability to degrade toxicants and they are ecologically safe in nature (Williams et al. 2003; Uniyal et al. 2019). Most of the fungal species commonly grow in soil, root, and foliar parts of plants, partially decomposed organic materials. It has high resistance capacity against potential toxic compounds such as heavy metals, emerging contaminants, pathogens as well as antibiotics. Different types of fungi like basidiomycetes and ascomycetes have been used in decolorization of natural and synthetic melanoidins from distillery wastewater and at the same time also generate fungal protein-enriched biomass for animal feed as a valuable product (Pant and Adholeya 2007).

Arikan et al. (2019) reported the contaminant removal capacity of two filamentous fungal species namely, *Aspergillus carbonarius* M333 and *Penicillium glabrum* Pg1 immobilized in macroporous polymeric support from textile wastewater. They studied the removal efficiency of color and chemical oxygen demand (COD) tested in two set up, i.e., batch experiments and continuously operated upflow packed bed bioreactor. The optimized pH was found 5.5 (4.5 to 6.0) for its higher removal potency to color and COD of wastewater. Results further indicated that color and COD removal efficiency from wastewater was found 98.2% and 69.8% for batch experiment and 78.8% and 67.7% for upflow packed bed bioreactor, respectively.

#### 6.5.2.3 Algal Biodegradation

Removal of potentially toxic substances from the wastewater by algal species termed as phycoremediation. Phycoremediation is a promising, efficient, eco-friendly, cost-effective technology. Generally, contaminants removal from wastewater works on the principle of adsorption and absorption; cell surface adsorption is independent on cell metabolism but in case of absorption or intracellular uptake depends on cell metabolism. The capability of algal species for the adsorption and absorption of contaminants depends on large surface area, higher metal binding affinity on their cell surface, feasible in metal uptake and storage systems (Ahmad et al. 2020). Natural ability of alga for uptake of nutrients and heavy metals, and degradation of organic contaminants is possible via symbiotic association with aerobic bacteria. Algae showed higher photosynthetic activity due to the presence of pigments and become greater source of oxygen in an aquatic ecosystem. They can also enhance the degradation of organic compounds in aerobic condition and helpful in biofuel production (Majumder et al. 2014; Gupta et al. 2020).

Ali et al. (2018) used *Scenedesmus obliquus* isolated from phytoplankton community of Nile River for the removal of pharmaceutical compounds from industrial effluents. Pharmaceutical residues are also considered as an emerging pollutant and have potential negative impacts on environment. Algal biomass was modified using alkaline solution and used for biosorption of different pharmaceuticals compounds namely cefadroxil, paracetamol, ibuprofen, ciprofloxacin, etc. At natural pH, 0.5 g/L of modified algal biomass has adsorption capacities for cefadroxil, paracetamol, ibuprofen, and ciprofloxacin as 68 mg/g, 58 mg/g, 42 mg/g, and 39 mg/g, respectively. Results further showed reusability of modified algal biomass for biosorption of different pharmaceutical compounds; its efficiency is decreased by 4.5% after three uses. However, there is a need to explore various algal remediation techniques as an eco-friendly alternatives for a better environmental condition.

#### 6.5.2.4 Integrated Aerobic-Anaerobic Biodegradation

Assessment of some important factors like composition and concentration of contaminants in wastewater, volume generation, cost-effectiveness, treatment susceptibility, environmental impacts, etc., is necessary for the selection of the best wastewater treatment technology. Wastewater treatments by a combination of aerobic and anaerobic degradation in an individual bioreactor have higher removal efficiency. Different engineering setups such as rotating biological contactor, membrane bioreactor, trickling filter, sequential batch reactor, etc., are used for aerobic degradation of contaminant. Upflow anaerobic film, membrane anaerobic reactor system, etc., are used for anaerobic degradation of contaminants in wastewater. Generally, these integrated approaches have been applied for removing higher level of organic matters from the wastewater. In the present time, awareness about these integrated approaches rapidly improved due to number of advantages, e.g., low chemicals requirement, less sludge production, higher resource recovery potential, less equipment requirement, and easy handling. Some disadvantages are also found related to this integrated approach such as membrane fouling, equipment malfunctions, and need of higher proficiency for its operation, but overall performance of these integrated approach is impressive (Goli et al. 2019).

Fazal et al. (2019) investigated the simultaneous removal of COD, nitrate, and sulfate from the wastewater using aerobic and anaerobic biodegradation approach. Medium properties, i.e., pH was the main determining factor for biodegradation of COD, nitrate, and sulfate. In aerobic treatment process, COD was degraded completely in $CO_2$ and $H_2O$, nitrate removal efficiency ranged from 83% to 90% in cellular metabolism. However, anaerobic process removes from 68% to 80% COD via methanogenesis process, nitrate removal efficiency ranged between 93% and 98%, sulfate changed into elemental sulfur from 85% to 97%. In anaerobic process, COD conversion rate was also found lower than those of the aerobic process. More studies are still required for integrated approach to enhance its contaminants removal efficiency, energy production as well as for reducing its operational cost and negative environmental impacts.

### *6.5.3 Molecular Approach*

Conventional microbial techniques for wastewater treatment are mainly based on pure culture isolation. The morphological, physiological, and biochemical assay of microbes extensively provided information of microbial biodiversity in natural and engineered systems. However, improving the efficiency of conventional wastewater treatment techniques using molecular approaches is very important. Molecular docking is important bioinformatics modelings in which contaminants bind with other substances and stabilized it (Liu et al. 2018). Molecular techniques such as cloning and gene library generation, fluorescent *in-situ* hybridization with DNA probes (FISH), and denaturant gradient gel electrophoresis (DGGE), etc., are also used in wastewater treatment. Although cloning and gene library generation are time-consuming processes they provide very significant taxonomical information. For identification of microbes at any desired taxonomic level, FISH techniques are used depending on the used probe specificity. DGGE is a simple and quick method for characterizing band patterns of different samples and sample profiling rapidly but genetic analysis is analyzed by particular band sequencing (Sanz and Köchling 2007).

Zahedi et al. (2019) assessed the eukaryotic waterborne pathogens in wastewater treatment plants (WWTPs) responsible for public health threat. In this study, they identified fecal pathogenic eukaryotes including *Cryptosporidium* sp., at different stages of treatment (initial or influents, intermediate and discharge, or effluents) in samples collected from 4 WWTPs in Western Australia, in which 3 WWTPs were used as stabilization ponds and one WWTP was used as activated sludge treatment technology. For next-generation sequencing (NGS), 18s rRNA of eukaryotic pathogen from wastewater as well as the mammalian blocking primer were used for reducing mammalian DNA amplification in wastewater. With the help of bioinformatics, 49 eukaryotic phyla were detected in wastewater samples, in which 3 phyla of human intestinal parasites, which were primarily detected in raw wastewater. Six subtypes of *Blastocystis* sp. and 4 *Entamoeba* sp. were identified by 18s NGS, but *Giardia* sp. and *Cryptosporodium* sp. were not detected. Real-time polymerase chain reaction was failed to detect *Giardia* sp. but detected *Cryptosporidium* sp. in WWTPs with the help of specific NGS. NGS is a more specific and reliable approach for detection of pathogen in wastewater and could be used in assessment of wastewater pathogen in future.

## 6.6 Conclusions

Rapid growth in population, urbanization, industrialization, and socio-economic development enlarge the gap between water availability and demand, particularly in semi-arid and arid area. Such problem can be avoided by enhancing water use efficiency or use of wastewater, i.e., domestic wastewater, storm runoff, and industrial effluents as an alternative water source. Long-term wastewater irrigation negatively affects the soil quality, e.g., salinization, reduced porosity, infiltration and hydraulic conductivity of soil, water repellency, reduced high bulk density, heavy metal contamination, and groundwater pollution. Agriculture sector is the major consumer of wastewater and considered not only as a valuable water resource but also has nutritive value. However, in the current scenario, safe use of wastewater is a matter of major concern as it is contaminated with potentially toxic elements. There should be development of suitable strategies for efficient and reliable use of wastewater and for reducing its negative impact on ecosystems, especially for water-scarce areas. In this chapter, wastewater availability and reuse at global and regional levels are briefly summarized and composition and characterization of wastewater are also highlighted. Long-term wastewater irrigation can adversely affect the physicochemical and biological properties of soil and pose risk to safety and quality of food through food chain contamination. Different control measures, i.e., physical, biological, and molecular for removing contaminants from wastewater are also discussed in brief. Abatement of contaminants in the wastewater irrigated soil using inorganic and organic amendments, bacterial inoculants, and cycling with qualitative water can provide a future research direction for developing eco-friendly, economically, and efficient management strategies for sustainable use of wastewater in agriculture. Success of sustainable wastewater reuse in different sectors of society mostly depends on public acceptance, public-private partnership model, and awareness spread by government and non-government organizations.

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