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Review article

Challenges and opportunities for using wastewater in agriculture: a review

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ABSTRACT

Use of wastewater for irrigating the agricultural land is becoming a common and a widespread practice throughout the world, particularly in arid and semiarid regions where freshwater resources are insufficient to meet water demand. According to estimates, 20 million hectares area on global scale is being irrigated with treated, partially treated and untreated wastewater, contributing to food security. Increasing water scarcity, industrialization, urbanization, increasing urban wastewater flows due to expanded water supply and sewerage services, nutrient value, consistency and reliability in supply are the key drivers for the widespread use of wastewater for irrigation. These drivers are expected to become even more powerful in the near future, making wastewater use in agriculture an emerging priority. Wastewater consists of mainly municipal wastewater, industrial effluents and storm water runoff. Wastewater is a potential resource for overcoming water shortage, and has both opportunities and challenges associated with its use. Wastewater can have multifaceted uses including urban and industrial uses, artificial groundwater recharge, crop land and landscape irrigation, aquaculture, and recreational and environmental uses. However, use of wastewater can involve potential risks such as harmful influences on plant growth, soil health and environment. It is also supposed to be the carrier of certain toxic substances including salts, heavy metals, pesticide residues, poisonous gases and a wide spectrum of enteric pathogens which have deleterious effects on crops, soil, air, groundwater, and eventually on human beings. Social concerns about using the produce of crops grown with wastewaters and subsequent influence on market value of these crops are also the main areas of thorough investigation. The present paper reviews the current literature on wastewater with focuses being made on its potential benefits and hazards on plant growth and soil health.

1. Introduction

Freshwater in all forms constitutes only 3% of the entire world's water. The other 97% is salt water. Of all the world's freshwater, about 70% is locked up in the Antarctic and Greenland icecaps, and most of the remaining freshwater is too deep underground to be accessible or is contained in soil moisture. This leaves only 1% of the world's freshwater available for withdrawal and human use. Furthermore, rapid socio-economic development and urbanization in recent years have made the freshwater insufficient to meet the basic needs of mankind in terms of agricultural, industrial and urban uses (Ashraf *et al*., 2017). This water shortage is becoming more acute in arid and semiarid regions due to uneven distribution of water resources both in time and space, and stronger competition for water demand among different sectors (Faryal *et al*., 2005). The emergent problem of water scarceness has significant destructive influence on economic development, human livelihoods, and environmental excellence all over the world. Water shortage can be overcome either by enhancing water use efficiency or using poor quality water (El-Kheir *et al*., 2007). In this respect, urban wastewater, which is readily and constantly accessible, is a promising resource to meet the gap between water demand and supply (Kashif *et al*., 2009). Wastewater use may helpful in water conservation, recycling of nutrients, reduction in input, and minimizing surface water pollution (Idris *et al*., 2007; Thapliyal *et al*., 2009; Vasudevan *et al*., 2010; Ahmed *et al.,* 2016; Kausar *et al*., 2017). Some other studies, for example, Kiziloglu *et al*. (2007); Nagajyothi *et al*., (2009); Nath *et al*., (2009); Palese *et al*. (2009) have demonstrated that use of wastewater in agriculture not only provides an alternative water resource but also helps to avoid the contamination of surface and ground water resources. Furthermore, it can improve the physical properties, nutrient contents of soils as well as crop growth and yield because it is rich in plant nutrients and organic matter. Matheyarasu *et al*. (2016) reported that wastewater reuse is an important component of sustainable water resource management, water reuse from various wastewater sources after removing the pollutants, salts and pathogens provides an option for water security.

The use of urban wastewater in agriculture is a centuries' old practice that is receiving renewed attention with the increasing population, urbanization and socio-economic development, particularly in arid and semi-arid regions of the world (Rosabal *et al*., 2007). Wastewater has been widely used as a low-cost alternative to conventional irrigation water, and it supports livelihoods and adds considerable value to urban and peri-urban agriculture, despite the associated health and environmental risks (Cooper, 1991). It has been estimated that approximately 80% of the urban raw and partially treated urban wastewater is being used for irrigation contributing to 70-80% food security and livelihoods in developing countries (Qadir and Schubert, 2002). In Pakistan, around 32500 hectares are used for growing vegetables with wastewater irrigation and expected to increase considerably in future (Saleem, 2005). The municipal wastewater discharge in ten big cities of Pakistan is estimated to about 5.3 million cubic meter per day which is also expected to increase greatly due to urbanization and socio-economic development (Anonymous, 2008). The reuse of wastewater has great environmental and economic benefits to society (Ghafoor *et al*., 1995; Qadir *et al*., 1998). It is constant in supply and is usually produced in large volumes, if not handled properly, would merely be discharged into the environment (Akram *et al*., 2002; Asano *et al*., 2007). Wastewater also contains significant amounts of organic and inorganic nutrients, especially nitrogen (N), phosphorus (P), potassium (K) and micronutrients (Ghafoor *et al*., 1995), and hence can save a lot of fertilizer expenditures when used in agriculture (Ibrahim and Sulmon, 1992).

On the other hand, wastewater effluents are high in electrical conductivity (EC) or total dissolved solids (TDS), sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and other mineral elements in toxic concentrations which limit their use in agriculture (Ghafoor *et al*., 1996). Murtaza *et al*. (2010) found that crops irrigated with raw wastewater accumulated higher concentrations of sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), ferric (Fe^{3+}), manganese (Mn^{2+}), zinc (Zn^+), lead (Pb^+), cadmium (Cd^{2+}), nickel (Ni^{2+}), chromium (Cr^{3+}), cobalt (Co) and mercury (Hg^{2+}) which can be accumulated in the soil during irrigation with wastewater and caused toxic effects on the crop growth and quality. Therefore, the utilization of wastewater for the irrigation of crops is associated with a number of risks. Very serious risks are those of crop yields reduction, fruit quality deterioration, soil contamination with metals and salts (Zavadil, 2009). Faryal *et al*. (2007) also demonstrated that irrigation of crops with untreated wastewater not only deteriorated the crop growth and fruit quality but also soil health. According to Mahmood and Maqbool (2006), major adverse effects associated with use of untreated wastewater include contamination of groundwater, build-up of heavy metals in soils and pathogenic hazards to farm workers. Most of the developing countries do not have ample resources to treat wastewater properly. Minhas and Samra (2003) reported that around 24% of wastewater generated in India by households and industry is treated before its use in agriculture. In Pakistan, the situation is more worse where only 2% of wastewater is treated (IWMI, 2003). Similar problems are found in other parts of Africa, Asia and Latin America (Scott *et al*., 2004). Consequently, wastewater in untreated, partially treated or diluted form is being used by farmers in urban and peri-urban areas to grow crops, particularly vegetables (Ensink *et al*., 2002; Murtaza *et al*., 2010).

Whatever the perception about the use of wastewater in agriculture, the fact is that wastewater irrigation has become a necessary evil, particularly in arid and semi-arid regions. The present review discussed the potential benefits and threats of using wastewater for crop production with focuses being made on its effects on crop quality and soil health.

2. Sources and composition of wastewater

Wastewater is generally consisted of domestic wastewater, institutional and industrial wastewater, storm water, and groundwater seepage entering the sewage network. The composition of wastewater varies markedly depending on the source of wastewater generation, method of collection and level of treatment (Imran, 2016). Antil and Narwal (2008) reported that on dry weight basis, wastewater contains more than 90% water while solid portion consists of 40-50% organic matter, 30-40% inert matter, 10-15% non-degradable material and 5-8% miscellaneous material. According to Gupta and Mitra (2002), in addition to other matters, wastewater contains different concentration of micronutrients such as Zn 2.8-11 ppm, Mn 1.6-15 ppm, Fe 5.6-205 ppm, Cu 0.6-1.9 ppm, Pb 1.5-40 ppm, Cd 0.15-5.80 ppm and Ni 1-6.4 ppm. Industrial wastewater usually contains high concentrations of heavy metals such as Pb, Ni, Cr, Hg, Cd etc. Wastewater also contains high concentration of salts, organic carbon and other suspended solids. Murtaza *et al*. (2010) reported that pH of wastewater usually ranges from 7.2-8.3, SAR 0.8-10.4 (mmol $L^{-1})^{1/2}$, N 8-106 ppm, P 4.2-53 ppm and K 19-2500 ppm. Saif et al. (2005) reported that wastewater mixed with industrial effluents used for irrigation in the vegetable growing area of Korangi, Karachi, Pakistan contains Zn 0.005-5.50 ppm, Cu 0.005-1.19 ppm, Fe 0.040-5.88 ppm, Mn 0.010-1.79 ppm, Cd 0.004-2.4 ppm, Cr 0.04-5.62 ppm, Ni 0.020-5.35 ppm, Pb 0.050-2.25 ppm, EC 2.02-45 dS m^{-1} and pH 6.00-8.88. According to Selim (2006) wastewater in Alexandria City, Egypt contains Na^+ 24.60, Ca^{2+} 1.50, Mg^{2+} 3.20, K^+ 1.80, Cl^- 62, SO_4^{2-} 35, carbonates (CO_3^{2-}) 1.10, bicarbonates (HCO_3^-) 6.60, ammonium (NH_4^+) 2.50, nitrates (NO_3^-) 10.10, P 8.50, Mn 0.20, Cu 1.10, Zn 0.80 meL^{-1}, EC 3.10 dS m^{-1}, SAR 9.30 (mmol $L^{-1})^{1/2}$ and pH 7.8.

3. Key drivers for using wastewater in agriculture

Decline in freshwater resources in terms of quantity and quality makes the use of wastewater a promising strategy for the conservation and expansion of existing water resources (Khan *et al*., 2013). Wastewater can be used for irrigating the agricultural land or landscape, aquaculture, industrial uses, environmental uses, recreational purposes, recharging of groundwater and many others, depending upon the level of wastewater treatment (Weldesilassie *et al*., 2010). The use of wastewater in agriculture is the most established and longstanding application because it requires relatively lower treatment level, nutritional value of wastewater and locating the agricultural lands in the vicinity of urban areas producing wastewater (Faryal *et al*., 2005). It has been reported that wastewater is being used to irrigate different crops on an area of 20 million hectares, worldwide (Ensink *et al*., 2004). The main inspirations for the use of wastewater in agricultural system are growing water stress (Baig *et al*., 2011), rapid urbanization, increasing food demand (Kauser, 2007), increasing wastewater discharges (Ensink *et al*., 2004), reliability and consistency in supply (Kausar *et al*., 2017), nutritional value (Imran, 2016), low cost, and increasing agricultural activities in the vicinity of main cities (Raschid-Sally et al., 2005). It is expected that use of wastewater in agriculture will become an emerging priority in near future as these drivers are becoming more powerful (Ashraf *et al*., 2013; Iqbal *et al*., 2017). Water stress and water scarcity are the global menace. It is expected that due to uneven distribution of water resources both in time and space, water scarcity may even develop in those regions which are thought to have sufficient water supplies (Faryal *et al*., 2005). Water stress is also expected to accelerate because of climate change. Global warming causes a rise in temperature which will result in glaciers melting, leading to initially frequent flooding but later on a severe water scarcity by the year 2050. Moreover, it is expected that the population in water-stressed and water-scarce regions will increase from 1.2 billion in 2007 to 4.0 billion by 2050. Climate change may also deteriorate the water quality in water stressed regions. As a result of growing water stress, demand for wastewater as an alternative water resource will rise, making it an integral element of local water supplies (Kausar *et al*., 2017). Another factor of increased use of wastewater in agriculture is growing urbanization. Currently, in developed countries, a larger share of world population is living in cities, while in developing countries urbanization is increasing very rapidly which leads to increasing freshwater demand and, in turn, wastewater discharges. It has been reported that urban population in developing countries is expected to increase from about 2.6 billion to 4.0 billion by the year 2030. The situation is more serious in in lower-income countries where urban population is expected to increase from 254 million to 539 million. Rapid urbanization and socio-economic development in developing countries is associated with a larger growth in urban wastewater generation (Matheyarasu *et al*., 2016). Kauser (2007) reported that due to rapid urbanization, more freshwater is being used to meet domestic needs, more than 70% of which returns as wastewater. So, increasing urbanization increases the generation of wastewater which if not used in agriculture would discharge to surface water bodies and contaminate the environment. Driven by rapid urbanization and growing wastewater volumes, wastewater is widely used as a low-cost alternative to conventional irrigation water, it supports livelihoods and adds considerable value to urban and peri-urban agriculture despite the associated health and environmental risks (Cooper, 1991). Globally, more than 1500 km^3 wastewater is produced per year which promotes urban agricultural activities significantly. Selim (2006) reported that total wastewater generation in Alexandria City, Egypt is currently 1.5 million m^3/day and expected to increase to 2.5 million m^3/day by the year 2020 which would have significant impact on agricultural activities.

4. Benefits of reusing wastewater

Increased water demand due to population pressure, depletion of existing water resources, rapid urbanization and industrialization, and environmental constraints such as global warming and low rainfall have forced the people to think about using the wastewater as an alternative source in many parts of the world (Iqbal *et al*., 2017). However, the main hindrance in the reuse of wastewater for purposes other than agriculture is the high water quality standards required, and the cost associated with achieving the desired quality (Asano *et al*., 2007). However, agricultural reuse requires only a moderate level of treatment (Weldesilassie *et al*., 2010). Moreover, it is of great advantage to plants and soil because of being rich in plant nutrients and organic matter (Ghafoor *et al*., 1995). The usage of wastewater in agriculture is especially beneficial for agricultural areas located adjacent to treatment plants or main cities. Water recycling for agricultural application is mostly practiced in arid regions of world (Kashif *et al*., 2009). The usual practice is to use municipal wastewater instead of industrial wastewater for agricultural purposes. The major constraints involved include loading of soils and groundwater with heavy metals, salts (Mahmood and Maqbool, 2006) and pathogens (Feachem *et al.* 1983).

Use of wastewater has a number of ecological as well as economic benefits (El-Kheir *et al*., 2007). Treated or untreated domestic and industrial effluents are generally discharged into natural water bodies such as rivers, lakes, canals and coastal marine estuaries, and are causing severe degradation of their environment (Lazarova and Bahri, 2005). Despite the legal restrictions and probable health issues, farmers of many developing countries use blended or cyclic, non-treated or partially treated wastewater for the irrigation of agricultural land because of its potential benefits (Keraita *et al*., 2008; Murtaza *et al*., 2010; Ashraf *et al*., 2013). Wastewater is a consistent, reliable and often only the available water resource for irrigation round the year (IWMI, 2003). It is uninterrupted in supply and generally discharged in bulks, predominantly as outflows from big cities sewage effluents (Rosabal *et al*., 2007). If these discharges are not brought into reuse, would simply be accumulated in the environment and damage its quality (Kashif *et al*., 2009). Wastewater irrigation often minimizes the requirement for fertilizer application as it is a rich source of plant nutrients, particularly N, P, K and micronutrients (Keraita and Drechsel, 2004). All types of sewage wastewaters contain considerable amounts of organic matter and mineral nutrients (Ghafoor *et al*., 1995). Therefore these waters could serve as an important fertilizer source after being treated and managed appropriately with the point of view of irrigation, and farmers can save a lot of fertilizer expenditure by using sewage water (Ibrahim and Salmon, 1992). In addition, soil microbial activities are also enhanced in response to irrigation with sewage water which might play an important role in improving soil health and crop yield (Meli *et al*., 2002; Ramirez-Fuentes *et al*., 2002). Wastewater even pumping from a source involves energy that is quite low in comparison with that required to pump clean water from deeper groundwater, thus minimizes irrigation costs (Buechler and Mekala, 2005). The main advantages of using wastewater for crop production have been summarized in Table 1.

Reusing the discharged effluents in agriculture certainly has considerable impact on decreasing or even eliminating the possible disastrous consequences of these wastes in their receptive environments. It has been reported that their agricultural reuse produces double benefits to environment, it removes wastewater from environment which otherwise discharges into the surface water bodies or on the land and will deteriorate the environmental quality, and on the other side, reduces the burden on the demand of freshwater from their long-lived natural pools (USEPA, 1992; Gregory, 2000; Qadir *et al*., 2007; Iqbal *et al*., 2017). Moreover, wastewater generates economic benefits of earning higher incomes from farming and selling high-value crops such as vegetables, which provide year-around job opportunities for farm labor. Sewage irrigation research and decision-making often focus on the health problems of food consumers and producers, the economic impact on producers' livelihoods as well as quality and price of food (Solley *et al*., 1998; Saleem *et al*., 2005). However, beneficial effects of wastewater vary considerably depending upon composition of wastewater as well as level of its treatment, need for using wastewater, and management strategies employed (Pettygrove and Asnao, 1985; Pescod, 1992; Lazarova and Bahri, 2005; Asano *et al*., 2007).

Table 1: Benefits of using wastewater in agriculture

Advantages	Mechanism	References

Reliable source of water	Available round the year, distinct from pluvial precipitation or seasonal streams	Drechsel *et al*. (2010)
Higher crop productivity	Year-round production, increased availability of wastewater permit farming in dry season	Keraita *et al.* (2008)
Farmers could get 3 to 5 times higher income	Wastewater reliability and nutrient values as well as low energy cost involve in wastewater irrigation	Huibers *et al.* (2004)
Multiple cultivation rotations and flexibility of crops grown	Wastewater use to raise vegetable and fodders in the vicinity of big cities	Raschid-Sally *et al*. (2005)
More balanced nutrition for plants	1000 m^3 municipal wastewater contribute 16-62 kg N, 4-24 kg P_2O_5, 2-69 kg K, 18-208 kg Ca, 9-110 kg Mg and 27-182 kg Na ha^{-1}	Koottatep *et al*. (2006)
Urban livestock production	Urban fodder production with wastewater	Drechsel *et al*., (2010)
Plant nutrients addition to soil. Solution of global P crisis.	Excreta and wastewater could be critical P sources	Qadir *et al*. (2007)
Higher gross margin (US$150 ha^{-1})	Farmers spent less on chemical fertilizer and gain more yield with wastewater	Rosemarin (2004)
Income source	In India, Mexico, Senegal, Ghana, and Kenya, wastewater based agriculture income lies between US$420 to $2800 ha^{-1} $year^{-1}$	Keraita *et al*. (2008)
Produce can be continuously sold at reasonable prices	Ability to produce crops at the time of their high demand	Cornish *et al*. (2001)
Higher land rent (2.5 times)	Consistency and reliability as well as nutrient values of wastewater	Jiménez (2005)
Empowers many farmers to go beyond the poverty line	Low investments and high and quick returns	Danso *et al*. (2002)

5. Challenges of reusing wastewater

The potential risks involved in using wastewater for irrigating crops are related to environment, crop and human health. These can be categorized into soil problems, health hazards, deterioration of ground water quality, and others. These problems are ultimately affecting the crops, human beings and animals and are inter-related with each other in a very complex manner (Ghafoor *et al*., 1996; Ensink *et al*., 2002; Minhas and Samra, 2003; Mahmood and Maqbool, 2006; Qadir *et al*., 2007; Murtaza *et al*., 2010; Ashraf *et al*., 2013; Kausar *et al*., 2017). Major challenges of using wastewater in agriculture are summarized in Table 2.

5.1. Environmental problems

5.1.1. Soil salinization

Currently, about 40% of the irrigated land in the world which has at least double productivity from that of rain fed land and is producing one third of the global food, is threatened by soil salinization (Hillel, 2000). This damage is mainly due to salinization induced by anthropogenic activities. The countries predominantly affected by salinization lie in arid and semi-arid regions of the world including China, Australia, India, Egypt, USA, Russia, Pakistan and many others (Ghassemi *et al*., 1991). The salt content of the wastewater used for irrigating crops is one of major factor for soil salinization, particularly in the vicinity of main cities

Table 2: Major challenges of using wastewater in agriculture

Hazard	Soil properties affected	References

Soil salinization	176% increase in soil EC, 485% increase in SAR, 0.3 units increase in soil pH, 172% increase in exchangeable Na and 34% increase in extractable B concentration with long-term use of wastewater	Rusan *et al.* (2007); Khai *et al.* (2008); Walker and Lin (2008)
Reduced soil porosity	Total porosity of wastewater irrigated land was decreased due to high Na in wastewater	Wang *et al*. (2003)
Water repellency	Soils that have been irrigated for more than 20 years with sewage effluent have developed water repellency which enhanced runoff and decreased the crop production	Wallach *et al*. (2005)
Reduced soil infiltration and hydraulic conductivity	Soil infiltration and hydraulic conductivity were decreased with wastewater high in Na	Tamminga (1995)
High bulk density	The wastewater irrigated soils usually have higher bulk density, especially at upper soil layers which promotes compaction and reduces porosity	Wang *et al*. (2003); Coppola *et al*. (2004)
Heavy metal contamination	Soil contamination with different heavy metals such as Cu, Fe, Zn, Mn, Pb, Hg, Cr, Co, Ni	Magesan *et al*. (2000); Ashraf et al. (2013)
Ground water pollution	EC, TDS, SAR and RSC of ground water taken from wastewater irrigated area exceeded the permissible irrigation water limits	Mahmood and Maqbool (2006)
	Heavy metal concentration of Mn, Pb, Hg, Cr, Ni, Fe, Cu, Co and Zn in ground water samples taken from waste water irrigated plots exceeded the permissible irrigation water limits	Mahmood and Maqbool (2006)
	Drinking of ground water taken from wastewater irrigated area caused diarrhea, dysentery and diarrhea with fever	Mahmood and Maqbool (2006)

where wastewater has been used for long time to produce vegetables and fodders (Murtaza *et al*., 2010). Furthermore, when wastewater is disposed off into water bodies, it increases their salt level. Salt content of wastewater is expressed in terms of EC or TDS. According to criteria developed by US Salinity Department, water having EC less than 1.5 dS m^{-1} or TDS less than 1000 mg L^{-1} of water is considered suitable for irrigating crops, and that having EC greater than 2.7 dS m^{-1} or TDS greater than 1800 mg L^{-1} is not suitable, whereas water having EC within the range of 1.5 and 2.7 dS m^{-1} or 1000 to 1800 mg L^{-1} TDS is considered to be of marginal quality (Mahmood and Maqbool, 2006). Wastewater induced soil salinization deteriorates soil quality, microbial biomass and microbial activity in the soil, whereas potentially mineralizable N in soil is also negatively correlated with EC (Rietz and Haynes, 2003). Saif *et al*. (2005) reported that wastewater mixed with industrial effluents and used for irrigation in the area of Korangi, Karachi, Pakistan have EC in the range of 2.02-45 dS m^{-1} and use of such wastewater without appropriate management increases salt buildup in soil and leads to soil salinization. According to Selim (2006), wastewater in Alexandria City, Egypt has EC 3.10 dS m^{-1} which is quite enough for the formation of saline soil when such water is used consistently for long period of time. Murtaza *et al*. (2010) reported that wastewater usually has EC higher than permissible limit and continuous use of wastewater without proper management degrades soil quality. Ashraf et al. (2013) used wastewater having EC 2.86 dS m^{-1} to irrigate tomato plants and found that wastewater without adequate management strategy not only decreased tomato growth and yield but also raised the salt buildup in soil.

5.1.2. Sodification

Wastewater containing excessive Na^+, when used for irrigation, results in greater concentration of this cation in soil compared with other cations such as Ca^{2+}, Mg^{2+} and K^+. Na^+ in irrigation water is, therefore, can be best expressed in ratio with these cations and the terms SAR and exchangeable sodium percentage (ESP) are usually used. Na^+ in higher concentration in wastewater used for irrigation distresses the permeability of the soil, leading to poor infiltration rate (Murtaza *et al*., 2010). This is due to Na^+ in higher concentration in the soil solution that replaces exchangeable Ca^{2+} and Mg^{2+} adsorbed to soil colloidal complex, resulting in soil particles dispersion. This dispersion causes the breakdown of secondary soil particles, a condition known as soil de-flocculation. Consequently, soil becomes compacted and hard on drying and lessened the water infiltration rates and air penetration through it, affecting its structure and biological activity (Ashraf *et al*., 2017). In addition, high pH, formation of earth crust, saturation of soil surface with water and anaerobic soil conditions are other problems allied with excessive Na^+ which are affecting the soil productivity. Soil microbial mass and activity are linearly decreased with increasing SAR and ESP of soil (Rietz and Haynes, 2003). Murtaza *et al*. (2010) reported that SAR of wastewater usually ranges from 0.8-10.4 $(mmol\ L^{-1})^{1/2}$ and continuous use of wastewater may cause sodification of soil. Saif et al. (2005) reported that high SAR value of wastewater generating from different industries might be an important factor for soil sodification. Selim (2006) also reported that wastewater in Alexandria City, Egypt have SAR value of 9.30 $(mmol\ L^{-1})^{1/2}$, and when this water is used to irrigate agricultural land without proper management may cause soil sodification. Many other studies, for example, Ghafoor *et al*. (1996), Ensink *et al*. (2002), Mahmood and Maqbool (2006), Faryal *et al*. (2007), Ashraf *et al*. (2013), Iqbal *et al*. (2017) reported that continuous use of wastewater may cause soil sodification depending upon the composition of wastewater and management/ treatment strategy.

5.1.3. Carbonates and bicarbonates hazard

High CO_3^{2-} and HCO_3^- present in larger concentrations in wastewater tend to increase salt buildup in soil (Minhas and Samra, 2003). When the soil solution is concentrated under dry conditions, CO_3^{2-} and HCO_3^- ions are combined with Ca^{2+} or Mg^{2+} to make precipitates of $CaCO_3$ or $MgCO_3$. The concentration of Ca^{2+} and Mg^{2+} with respect to that of Na^+ declines and resulting in higher SAR index, leading to alkalization and increased pH (Ghafoor *et al*., 1995). Thus, when water analysis indicates high pH, there may be signs of higher CO_3^{2-} and HCO_3^- content. According to Murtaza *et al*. (2010), wastewater contains high concentration of CO_3^{2-} and HCO_3^- while pH in the range of 7.2-8.3, and continuous use of such wastewater for longer time increases CO_3^{2-} and HCO_3^-, and thus deteriorates the soil health. Qadir *et al*. (2007) also reported that wastewater carries different concentration of CO_3^{2-} and HCO_3^- which accumulate in soil at higher concentration when wastewater is used in agriculture for long period of time. According to Selim (2006), wastewater having CO_3^{2-} 1.10 meq L^{-1} and HCO_3^- 6.60 meq L^{-1} may deteriorate soil quality when used for irrigation without proper management. Some other studies, for example, Ghafoor *et al*. (1995), El-Kheir *et al*. (2007), Ashraf *et al*. (2013), Kausar *et al*. (2017) also reported higher accumulation of CO_3^{2-} and HCO_3^- in soil with use of wastewater of varying composition.

5.1.4. Heavy metals

Heavy metals buildup in soils irrigated with wastewater has been reported by many studies (Saif *et al*., 2005; Selim, 2006; Maldonado *et al*., 2008; Ashraf *et al*., 2013; Iqbal *et al*., 2017). These metals are the elements with atomic weight between 63.5 and 200.9 and a specific gravity higher than 4.0 (Kennish, 1992). Some of heavy metals are needed by living organisms in trace amount, yet excessive amount of any of these metals may be detrimental to the living organisms. Therefore, heavy metals in wastewaters are of a serious concern regarding to pollution of soil and surface water bodies (Kennish, 1992). Out of these, the potential harmful effects of Pb, Hg, Cd and Cr to human beings and the environmental quality are well documented. Among these, Pb, Hg and Cd have no useful function known in biological organisms (Anonymous, 2002). Tariq et *al*. (2006) reported that industrial wastewater in Peshawar contained high concentration of different heavy metals such as Pb (0.646 ppm), Cr (51.70 ppm) and Fe (14.54 ppm), and use of such industrial wastewater without proper management could pose severe threat to soil health and food quality. Similarly, Chatterjee *et al*. (2002) reported high concentration of heavy metals in industrial wastewater, producing damaging effects on soil health and crop yield. Azeem (2009) analyzed the wastewater from industries present in Kot Lakhpat industrial zone, Lahore and reported higher concentration of Cd, Fe, Cr, Zn and Pb in wastes. According to Behbahaninia and Mirbagheri (2008), application of untreated wastewater and sewage sludge to agricultural lands causes the accumulation of heavy metals in soils up to levels that may pose long term potential environmental and health related problems. Long term use of wastewaters contaminated with heavy metals results in building up the concentrations of some of these heavy metals in soil potentially beyond hazardous levels, however, their accumulation in plants is not up to much greater extent probably due to the physicochemical characteristics of soils that prevent their movement to plant roots (Oflosu-Asiedu *et al*., 1999; Mireles *et al*., 2004; Khan *et al*., 2008). However, the concentrations of some of these elements, especially Ni, Pb and Zn in soil irrigated with wastewater are higher than the maximum permissible limits indicating some degree of contamination and crops grown on these soil show higher levels of these elements especially Ni and Cd beyond the maximum permissible concentrations (Qishlaqi and Moore, 2006).

However, the uptake and accumulation of these elements by crops depend upon the source of wastewater, nature of crop and soil characteristics, and usually not up to that level as found in wastewater or soil in which these crops are grown. Kashif *et al*. (2009) reported that among a number of vegetables irrigated with the same source of wastewater, the order of toxic heavy metal contamination or transfer factor from soil to plant was spinach (*Spinacia oleracea*) > ghiya tori (*Luffa aegyptiaca*) > okra (*Abelmoschus esculentus*) > green chillies (*Capsicum annum L.*) > tar (*Cucumis melo*) > brinjals (*Solanum melongena*). The fiber crops such as cotton (*Gossypium hirsutum* L.) and flax (*Linum usitatissimum*) grown in heavily contaminated soils accumulated significant quantities of these metals, however their leaf and seed concentrations are much less than that in respective soil (Angelova *et al*., 2004). Similarly, grains of paddy (*Oryza sativa* L.), irrigated with untreated effluent from paper mill, contained some concentration of heavy metals but this concentration was far below than that found in effluent or soil (Fazeli *et al*., 1998).

In Pakistan, however, there is an alarming situation with respect to heavy metal content in soils and crops irrigated with wastewater. For example, soils and vegetables irrigated with the wastewater of Hudiara drain (a natural storm water channel originating from India and entering Pakistan near Hudiala village) were found to be higher in DTPA-extractable metal concentrations far above than Indian permissible limits for safe consumption of vegetables (Kashif *et al*., 2009). The soils and vegetables such as spinach (*Spinacia oleracea*), ghiya tori (*Luffa aegyptiaca*) and tomatoe (*Solanum lycopersicum*) irrigated with untreated industrial water near korangi Industrial Area of Karachi were rich in all heavy metals (Cd, Co, Cr, Cu, Fe, Pb, Hg, Mn, Ni and Zn), with Pb being the highest and Hg was lowest in concentration (Raza, 2005).

5.1.5. Groundwater pollution

Indiscriminate use of sewage effluents, especially in suburban areas for crop irrigation is a usual practice (Murtaza *et al*., 2010). In addition to the adverse effects of sewage irrigation on soils, crop yield and quality, its impact on groundwater is much greater than it could commonly be conceived (Sial *et al.,* 2005). Direct irrigation by wastewater has resulted not only in salinity, sodicity and heavy metals problems, but also deteriorated groundwater quality by its high salts and heavy metal content (Sial *et al*., 2005). Any substance that is easily soluble and penetrates the soil may become a source for groundwater pollution. The long term wastewater irrigation could increase the mobility of metals present in soil because of the formation of water soluble complexes with organic ligands present in wastewater which are easily leachable through soil profile, eventually reaching groundwater, deteriorating its quality (Rosabal *et al*., 2007). Groundwater is a long-standing pool of the natural hydrological cycle, in contrast to short-term and comparatively unstable water reservoirs like the water vapors and fresh surface water resources. Mahmood and Maqbool (2006) reported that groundwater in areas irrigated with effluents of industries such as Chakra village in Faisalabad, Pakistan was found to contain quantities of heavy metals higher than those recommended by National Environmental Quality Standards (NEQS) especially Mn, Cu, Co and Zn. The presence of these contaminants in groundwater is extremely dangerous as groundwater is used by humans for drinking without any treatment. They further reported that groundwater pollution could have overwhelming effects because once groundwater is contaminated, it requires very costly operation to remove the pollutants. The major groundwater contamination problems are nitrate pollution, heavy metals retention and pathogenic threats to consumers (Hammer and Hammer, 1996).

A number of pollutants have been found to be present in ground water. The one of these is nitrate (NO_3^-) which is imported from the natural ecosystems, run-off from gardens and lawns, farm lands subjected to intense fertilizer applications, livestock sheds, municipal and livestock waste treatment systems, septic tanks, poultry litter and manure, and lagoons into groundwater. Nitrates in high concentration exceeding 10 mg L^{-1} as N in water makes it unsafe for drinking purpose (Erickson, 1998; Garland and Erickson, 1994; Cox and Kahle, 1999; Erickson and Matthews, 2002; Erickson, 2000; Mitchell *et al*., 2003). Nitrates are drained-out of system by volatilization, denitrification, leaching and immobilization. Leaching of NO_3^- is of utmost concern regarding groundwater quality. The dynamics of NO_3^- leaching are dependent upon soil characteristics, rainfall amounts and irrigation systems. Sandy soils with high rainfall or intensive irrigation are prone to higher leaching rates (Tyson *et al*., 1992). The municipal wastewater is one of the sources of NO_3^- pollution in groundwater and reuse of even treated municipal wastewater, which appears to be a sensible approach for applying wastewater to crops, was found to have high levels of various forms of N, easily convertible, if used extensively in farmland, may contaminate groundwater (Pettygrove and Asano, 1985). Nitrate in drinking water may cause methemoglobinemia, or 'blue baby syndrome' in children of age group below six months (Page *et al*., 1983). Sophocleous *et al*. (2010) reported a high NO_3^- -N concentration (10-50 mg kg^{-1}) in the silty clay loam soils and deeper vadose zone, and also in the underlying deep (20-45 m) groundwater as a result of crop irrigation with secondary-treated municipal wastewater. The ground water of Mexico City, where the crops have been irrigated with untreated city wastewater for long period of time was found to be higher in NO_3^-, and risk of methemoglobinemia for young children and infants has been increased (Downs *et al*., 1999; Gallegos *et al*., 1999). Rodgers *et al*. (2003) reported that groundwater aquifers of soils irrigated with dairy wastewaters were found to contain some concentration of NO_3-N. The significant NO_3^- leaching was observed in free draining sandy loam soils irrigated with a depth above 25 mm of dairy wastewater. Downs *et al*. (1999) reported that groundwater of the Mexico City where untreated wastewater had been used for crop irrigation for decades, showed target and non-target organic compounds, chlorinated pesticides, polychlorinated biphenyls as well as microbiological contaminants - *Vibrio cholerae*, Salmonella and Coliforms. The community using this groundwater was found to be affected by diarrhea (10% people), persistent skin irritations (9% people) and people drinking inadequately sterilized groundwater were at possible risk of gastrointestinal disease. Another study at Mexico City also reflected similar results showing the elevated concentrations of fecal and total coliforms in subsurface water especially at shallower depths (<10 m below the surface), and during the wet season. Thus, wastewater irrigation proved to have a hazardous impact on ground water quality (Gallegos *et al*., 1999).

5.2. Health problems

There is a greater concern of crop, animal and public health associated with wastewater irrigation on account of its salt content, toxic metals concentration and pathogenic levels (Sheikh-Ol-Eslami *et al*., 1979; USEPA, 2004; Ashraf *et al*., 2013; Iqbal *et al*., 2017). It has been well documented that food produced using wastewater might be contaminated with bacteria, fungi, nematodes, viruses and protozoans that could cause various diseases in humans and other living organisms (Tanner, 1944; Wang and Dunlop, 1954; Geldreich and Bordner, 1971; Jackson, 1970; Bryan, 1977; Kowal *et al*., 1980; Murtaza *et al*., 2010, Kausar *et al*., 2017). Therefore, from point of view of health, it is also required that wastewater treatment should be carried out to get rid of harmful substances and microorganisms before using it for irrigation. Major diseases associated with wastewater irrigation are summarized in Table 3. Since, wastewater contaminated with pathogenic organisms is mostly used to raise vegetables, such vegetables contained considerable quantities of pathogens which might cause several diseases in humans and other organisms (Geldreich and Bordner, 1971; Larkin *et al*., 1978; Epstein *et al*., 1982; Asano *et al*., 2007). This is especially true in case of vegetables eaten in fresh form, since the microorganisms that get deposit on their surface survive for several weeks and upon eating these vegetables, pathogenic diseases such as diarrhea, shigellosis, salmonellosis etc. are caused (Rudolfs *et al*., 1951; Dunlop and Wang, 1961; Kowal *et al*., 1980; Saif *et al*., 2005). However, little or no public concern exists concerning pathogens by the use of wastewaters and bio-solids in cereals (Crute *et al.,* 2003). According to Rosas *et al*. (1984), among vegetables used as raw, the bacterial counts varied between dipped and unrinsed edible portions with the highest bacterial counts in leafy vegetables such as lettuce (*Lactuca sativa*) and spinach (*Spinacia oleracea*) indicating that their consumption posed greater health risk. However, some scientists reported that the consumption of raw vegetables including carrots (*Daucus carota*), cucumber (*Cucumis sativus*), cauliflower (*Brassica oleracea*), and lettuce (*Lactuca sativa*) irrigated with partially treated wastewater effluents did not increase the incidence of infections in people belonging to all age categories (Peasey *et al.,* 2000). According to the findings of World Health Organization, the World Bank and the International Reference Centre for Waste Disposal, major health hazards of wastewater irrigation are the spread of intestinal nematode infections into labor working in wastewater irrigated fields as well as consumers of vegetables harvested from these fields. These diseases occur due to transmission of intestinal parasites such as roundworms, whipworms and hookworms and fecal bacterial diseases such as dysentery, bacterial diarrhea, cholera and typhoid to the crop consumers (IRCWD, 1985; Shuval *et al*., 1986; Prost, 1988; WHO, 1989). The microbial pathogens causing diseases in humans, mostly occurring in wastewaters are of enteric origin and gain their entry into environment through the excreta of infected hosts and then directly through the drainage, contaminated sewage or indirectly through escape from the soil or any other land surface enter into waters (Feachem *et al.,* 1983). Types of enteric pathogens contaminating the water include bacteria, protozoa, viruses and helminths. The risk of water-borne diseases from any of these pathogens could be dependent on number of factors, including the number of pathogens and degree of their dispersal in water, the infection dose needed and the host susceptibility, the degree of fecal contamination of water and extent of treatment carried out before the potential exposure to water (Haas *et al.,* 1999). Nematodes and tape worms, collectively known as helminths are well-known intestinal parasites causing infection through fecal-oral route (Toze, 1997). One of the main sources of helminth spread throughout the world is the use of untreated or partially treated sewage wastewater and sludge to irrigate crops that are used as food (WHO, 1989). In Mexico, the incidence of roundworm infection was higher in farm labor and their children working in untreated sewage water irrigated fields compared with other people (Peasey *et al*., 2000). A few of these parasitic organisms are dependent upon another intermediate host before developing virulence. Commonly observed helminth parasites in wastewaters that have considerable health risks in wastewaters are round worm (*Ascaris lumbricoides*), hook worm (*Ancylostoma duodenale* and *Necator americanus*), and the whip worm (*Trichuris trichiura*). These helminths have no intermediate host and a simple life cycle, and are able to cause infection through fecal-oral route (Toze, 1997). The most commonly found microbial pathogens in wastewaters are bacteria (Toze and Hanna, 2002). Many of the bacterial pathogens are enteric in origin, however, wastewater also contains some bacterial pathogens e.g. *Legionella* spp., *Mycobacterium* spp., and *Leptospira* which are non-enteric in nature (Wilson and Fujioka, 1995; Fliermans, 1996; Neumann *et al*., 1997). Theoretically, bacterial pathogens are capable of self-replication in their environment, even outside the body of their host (Haas *et al.,* 1999; Toze and Hanna, 2002). Enteric viruses are the smallest of the pathogens found in wastewater mostly in sewage effluent mainly containing fecal contaminated water (Ward *et al.,* 1986). These viruses lack the ability to replicate outside the host cell in wastewater but when they enter the suitable host, force the host cell to self-replicate themselves (Toze, 1997). Only human fecal contamination of water is the one that should be considered to be an issue for human viral infection, since most of the enteroviruses have a narrow host range meaning that most of the viruses in wastewater infect humans but do not harm other animals (Haas *et al.,* 1999). Enteric protozoan pathogens are single-cell eukaryotes that are obligate parasites. Outside host, they go in dormancy stage and called cysts or oocysts. Infection from these protozoans could occur after intake of food or water contaminated with the oocysts or via man to man contact (Carey *et al.,* 2004). There exists a variety of protozoan pathogens in wastewaters and recycled water sources (Gennaccaro *et al.,* 2003). The most commonly observed are *Cryptosporidium parvum, Entamoeba histolytica,* and *Giardia intestinalis* (Toze, 1997). *Giardia* and *Cryptosporidium* are universal in fresh and sea waters and have been reported from many countries around the world (Ho *et al*., 1995, Kfir *et al*., 1995; Ferguson *et al*. 1996, Haas and Rose, 1996; Wallis *et al*., 1996). *Entamoeba histolytica* is present in all parts of the world, although it is more widespread in tropical countries (Feachem *et al*., 1983).

Table 3: Major diseases associated with wastewater irrigation

Disease	Causal organism	Route of infection	Risk order	References
Helminthiases, Ascariasis, Schistosomiasis, koilonychias	Helminths (parasitic worms), intestinal nematodes, hookworm	Mainly soil contact outside home and food	High	Ensink *et al*. (2002); Silva and Scot (2004)
Cholera, salmonellosis, typhoid, shigellosis, gastric ulcers	Bacterial infections (*Vibrio cholera, Helicobacter pylori*)	Mainly home contact and food or water	Low	Blumenthal and Peasey, (2002)
Giardiasis and amoebiasis	Protozoan infections	Mainly home contact and food or water	Low	Blumenthal and Peasey (2002)
Viral gastroenteritis and infectious hepatitis	Viral infections	Mainly home contact and food or water	Least	Shuval *et al*. (1986)

6. Wastewater management strategies

The proper cure of wastewater is of course its treatment using physical, chemical and biological methods. However, due to lack of financial and technical facilities, it is not possible to treat whole of the wastewater produced, particularly in developing countries. Adequate management of wastewater used in agriculture can provide an efficient and viable strategy for alleviating its deleterious effects. These management strategies comprise of selection of suitable crops which are not directly consumed by humans such as forest trees (Lazarova and Bahri, 2005), irrigation practices with no or minimum contact of wastewater with plants and farm workers (Asano *et al*., 2007), cyclic and blended use of wastewater with freshwater (Faryal *et al*., 2007), use of chemicals such as gypsum and organic amendments (Khan *et al*., 2013), adequate plant nutrition (Ashraf *et al*., 2013), inoculation with metal detoxifying bacteria (Madhaiyan *et al*., 2007), protective measures by farm workers before exposure to wastewater (Scott *et al*., 2010), thorough washing of vegetables grown with wastewater before use (Ensink *et al*., 2007), protective measures (Rosabal et al., 2007), and awareness campaigns (Saleem, 2005).

7. Conclusion and future perspectives

Rapid socio-economic development, industrialization and urbanization in recent years have widened the gap between water supply and demand, particularly in arid and semi-arid regions. This situation can be overcome either by increasing water use efficiency or using poor quality water as an alternative water resource. Water resource planners and researchers are considering wastewater as an alternative to irrigation water for a long time. Powerful drivers for the use of wastewater in agriculture are growing water stress, increased generation of wastewater, increasing food demand, improved sewerage facilities, consistency and reliability of wastewater supply and its nutritional values. These factors are expected to become more influential in near future, making the reuse of wastewater as an emerging priority in developing agricultural programs. Currently, about 20 million hectares of farmland have been irrigated with wastewater throughout the world, and thus makes a significant contribution to the food security. In Pakistan, wastewater discharges are also growing rapidly, particularly in big cities which are mostly used to raise vegetables and fodders in the vicinity of urban areas. It has been estimated that about 32500 hectares of farmland are cultivated with wastewater irrigation in the country. However, wastewater may contain different toxic substances such as gases, heavy metals, mineral salts, pesticide residues and poisons which have damaging effects on plant growth and development, soil health, groundwater quality, environmental health and ultimately human beings, particularly when used without appropriate management practices. Many treatment strategies such as evaporation, cementation, ion exchange, solvent extraction, and membrane processing have been currently used to remove the harmful substances from wastewater. However, these strategies need higher start-up and running expenditures, and are difficult to adopt in developing countries. In comparison, different management strategies such as use of mineral nutrients, organic amendments, bacterial inoculation or blending and cycling with good quality water can provide a research direction for developing an environment-friendly and economically viable management strategy for the efficient and sustainable use of wastewater to irrigate farmlands.

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