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Assessment of potential risks associated with chemicals in wastewater used for irrigation in arid and semiarid Zones (A review)

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Abstract:

Irrigation with raw, partially and treated wastewater is a widespread practice in many arid and semi-arid zones. The importance of wastewater for agriculture has increasingly been recognised not only as a valuable water resource but also for its nutrient value. However, inappropriate management of irrigation with wastewater can pose substantial risks to public health and the surrounding environment as a result of its microbial and toxic components. In this review, we summarise recent research and provide a broad overview of the potential risks associated with the chemicals in wastewater used for irrigation including their environmental, and health impacts, factors that may affect the fate of these chemicals, and available mitigation methods and management options to reduce their impacts. A primary aim of this review is to construct a generalised ranking of the risks from the chemical constituents of wastewater used for irrigation in arid and semi -arid zones.

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Keywords: irrigation with wastewater, environmental risks, chemical constituents, wastewater management, arid zones

Introduction

Water scarcity is a growing concern especially in many arid and semi-arid zones where the limited natural water resources are heavily exploited. Increasing water scarcity threatens economic development and the sustainability of human livelihoods as well as the environment especially in developing countries (Scott et al., 2004).

The challenges posed by water scarcity will become even greater in the future due to population growth, urbanisation, climatic change and the growing food demand which will contribute to increasing the gap between water supply and demand for water(Hussain et al., 2002). It is estimated that around 40% of the global population are currently experiencing water stress (Calzadilla et al., 2011)

Globally, agriculture is the largest consumer of water, accounting for approximately 70% of all freshwater extraction (Winpenny et al., 2010). Due to growing competition between the agricultural and higher-economic-value urban and industrial uses of freshwater supplies as a result of the increasing demand for water, wastewater has increasingly become the predominant low cost and reliable alternative to conventional irrigation water in many countries especially arid and semi-arid zones (Scott et al., 2004). Currently, reuse of wastewater in urban and peri-urban agriculture is already a widespread practice in different parts of the world (Jiménez et al., 2010, Winpenny et al., 2010). It estimated that at least 10 % of the global population consume foods produced by irrigation with wastewater (WHO, 2006) and more than 20 million hectares are irrigated with untreated, partly treated/diluted or treated wastewater around the world (Jiménez et al., 2010). It also has been reported that approximately 44 countries are reusing over 15 million m^3/day of reclaimed water for irrigation purposes (Winpenny et al., 2010)

To a large extent, wastewater can be considered as a reliable source of water and nutrients that is available all year around. Its availability and nutrient properties are important factors that make it a valuable resource particularly in arid and semi-arid zones (Jiménez et al., 2010, Winpenny et al., 2010). Nevertheless, wastewater is a complex resource and while it may have many benefits, concern regarding the risks to human health and environmental quality as a result of the microbial and toxic components is a serious obstacle for wastewater reuse in agriculture. Most of the existing research has tended to focus on the microbial risks regarding the use of wastewater and guidelines for the safe use of wastewater in agriculture. This may be due to the immediate effects of microbiological components on public health compared to the longer term risks posed by chemical exposure ((WHO, 2006, Bos et al., 2010). Generally, using wastewater in agriculture is unlikely to contribute to direct health impacts from chemicals hazards unless the wastewater is heavily contaminated with discharges from industrial sources. Another explanation may be the difficulty in assessing the health impacts of toxic chemicals in wastewater as it usually has a long latency period (Bos et al., 2010).

Inappropriate management of wastewater irrigation can contribute to serious environmental problems especially in arid and semi-arid zones where wastewater could be the predominant water supply for agriculture (Pescod, 1992, Ayers and Westcot, 1985, WHO, 2006, Simmons et al., 2010). Wastewater irrigation could lead to negative impacts on soil properties and fertility, crop yields, groundwater and surface water quality, and the aquatic ecosystem. The magnitude of the potential impacts will depend on the concentration of the chemicals, their solubility and inherent toxicity. Other important factors the rate and frequency of wastewater application, the type of crop, and target yields, inhertent soil properties and condition, the vulnerability of the aquifer, climatic conditions, and technology level and the social-economic status of the farmers. In order to ensure good crop yields and minimise the environmental risks associated with the chemical constituents in wastewater, a risk assessment should be carried out and appropriate mitigation measures should be applied. That will require an understanding of the fate, transport and availability of these chemicals within the environment. Most of the environmental studies in last few decades have primarily focussed on the effects and management of salinity and heavy metals although more recently some studies have also addressed the effects of other chemical constituents of wastewater such as emerging contaminants.

This structured review attempts to provide a comprehensive overview of the environmental impacts and risks from irrigation with wastewater particularly in arid and semi -arid zones. The main objectives of this review are: (1) provide a review of the chemicals present in raw, partially and treated wastewater used for irrigation, (2) provide a review of the impacts of these chemicals on the environment (soil, plant, water resources) and health from irrigation with wastewater, (3) identify the factors that could influence their fate in the environment (4) review the available mitigation and management options to allow the reuse wastewater for irrigation; (5) rank the risks from these components based on the potential and the significance of their effects on arid and semi- arid zones

Negative impacts from the chemical constituents in wastewater used for irrigation

Wastewater contains various types and concentrations of contaminants depending on its source and the degree of treatment. In general, the critical water quality problems in relation to the chemical risks from wastewater reuse for irrigation are excessive concentrations of salt, heavy metals, nutrients, toxic organic compounds, and organic matter (WHO, 2006, Toze, 2006a, Qadir and Scott, 2010, Qadir et al., 2015).

The likelihood and magnitude of their negative impacts depends on their concentration, their solubility and inherent toxicity together with rate and frequency of wastewater application, the type of crop, and target yields, inhertent soil properties and condition, the vulnerability of the aquifer, climatic conditions, and technology level and the social-economic status of the farmers. (WHO, 2006). In the following sections, findings relating to each of the five main topic areas are summarised.

1.1. Excessive levels of Salt

Wastewater usually has a higher concentration of total dissolved solids and major ions and a higher electrical conductivity than fresh water especially in regions with hot climates due to the long dry season and the high rate of evaporation. These can originate from many sources such as detergents and washing material, the chemicals used during the treatment process and other sources (Toze, 2006a, Qadir and Scott, 2010, Muyen et al., 2011, Becerra-Castro et al., 2015).

Conventional wastewater treatment processes are inefficient for the removal of excessive salt and sodium (Bahri, 1998). Generally, salt removal requires advanced treatment such as reverse osmosis or the use of cation exchange resins which are very expensive and may, therefore, be uneconomic for the production of water for irrigation (Qadir and Scott, 2010, Chen et al., 2013a, Toze, 2006a). If excessive salt is not removed, it may result in accumulation in the soil, particularly in the topsoil as a result of high rates of evaporation. It may also lead to elevated levels of exchangeable sodium concentrations and the exchangeable sodium cation (Na^+) percentage (ESP) (Qadir and Scott, 2010, García and Hernández, 1996, Rietz and Haynes, 2003, Hamilton et al., 2005). For example, a study conducted in Jordan shows that irrigation with wastewater increased soil salinity two to three times compared to a control site (Al-Zu'bi, 2007). It was also found that long-term wastewater irrigation (up to 80 years) in the Valley of Mezquital in Mexico led to increasing soil salinization, and especially Na saturation (Friedel et al., 2000). Another example from arid and semiarid western USA shows that irrigation with recycled wastewater has exhibited 187% higher EC and 481% higher sodium adsorption ratio (SAR) Compared with sites irrigated with fresh water(Qian and Mecham, 2005).

It has been estimated that an annual application of 1000 mm of irrigation water with 500 mg/l of TDS may lead to an additional 5 tons/ha/year of salt in the soil unless it is properly drained (Muyen et al., 2011). Increased soil EC, exchangeable Na and ESP has significant effects on soil properties and plant growth and can result in a decrease in soil productivity and crop yields. A study conducted in 1993 showed that irrigation with wastewater increases Maize and Sorghum crop yield until the salinity level reached 2330 mg/l TDS) after which the yield slightly decreased (Muyen et al., 2011). It may also contribute to groundwater pollution particularly in areas with shallow groundwater (Qadir and Scott, 2010, García and Hernández, 1996, Rietz and Haynes, 2003, Hamilton et al., 2005). Table 1 provides a summary of the main potential effects from the excessive level of salts and sodium in wastewater.

1.1.1. Factors influencing the impacts of salinity and sodicity:

Salinity and sodicity- related characteristics and impacts are affected by many factors including: the type of salt, the efficiency of leaching and the drainage system, irrigation system type, sensitivity of crops, and soil properties (Ayers and Westcot, 1985, Mohammad and Mazahreh, 2003, Rietz and Haynes, 2003, Chen et al., 2013a, Simmons et al., 2010, Hamilton et al., 2005, Malash et al., 2005, Leal et al., 2009). As a result, the significance of the salinity and sodicity risk will vary greatly under different wastewater irrigation regimes.

The suitability of reusing wastewater for irrigation is not only affected by the quantity of dissolved salts but also by the type of salts that are present (Maas and Grattan, 1999). Generally, wastewater can be classified into saline wastewater that contains excess levels of soluble salts and TDS, sodic wastewater containing excess sodium Na^+, and saline-sodic wastewater which is characterised by both excessive salt and sodium Na^+. The type and the degree of the effects will vary depending on the type of wastewater being reused. (Simmons et al., 2010, Hillel, 2000).

Significant long-term problems of soil salinity and/or sodicity due to the application of saline irrigation water results primarily from poor irrigation management and inadequate soil drainage systems (Simmons et al., 2010, Carr, 2011). This is more pronounced in arid and semi- arid zones where rainfall is low and there are high rates of evaporation meaning accumulated salt ions are rarely removed naturally from soils by leaching or flushing (Emongor and Ramolemana, 2004, Simmons et al., 2010) .

The type of irrigation system used directly affects both the efficiency of water use and the way salts accumulate. Each irrigation technique has certain advantages and disadvantages and these should be considered in order to improve salinity control (Maas and Grattan, 1999). For example, while sprinkler irrigation can improve salt leaching downwards below the root zone, it can increase the effect of ion toxicity as the salt may accumulate in the leaves of certain sensitive crops. (Hamilton et al., 2005, Simmons et al., 2010). Drip systems may be recognised as more efficient when using saline water, however they can lead to salt accumulation between drip points due to radial water movement in the soil (Chen et al., 2010a, Malash et al., 2005, Hamilton et al., 2005, Al-Nakshabandi et al., 1997).

The toxic effect of excessive salt and major ions on crops depends on the type of crop and the stage of growth (Maas and Grattan, 1999, Hillel, 2000). Some crops are more tolerant to excessive salt than others and in general, salt tolerance can be divided into four classes: sensitive, moderately sensitive, moderately tolerant, and tolerant (Maas and Grattan, 1999, Simmons et al., 2010, Hillel, 2000). Salt sensitivity changes significantly during plant development with most crops being relatively salt tolerant during germination. Substantial evidence indicates that the early seedling period is the most salt- sensitive stage and the plant becomes increasingly tolerant as its growth proceeds. In addition, certain parts of plants uptake salt ions more readily than others, for example, $Na^+$and Cl^- entry into many horticultural crops is easier through the leaves than the roots (Maas and Grattan, 1999, Hamilton et al., 2005, Munns and Gilliham, 2015). Soil texture and mineralogy is a dominant factor affecting soil salinity and sodicity. Field investigation shows that salts may be leached downwards more easily in loamy and sandy soils compared to soils with a high clay content as they may be intercepted by clay particles (Chen et al., 2013b). It has also been found that soils that have more clay content are more susceptible to sodic conditions (Qadir and Schubert, 2002, Qian and Mecham, 2005, Leal et al., 2009). Organic matter and organic carbon also influence the impacts of excessive salts and sodium. Adding organic matter to soil can enhance the total porosity and subsequently increase the hydraulic conductivity and holding capacity leading to a reduction in the adverse effect of excessive salts particularly when using sodic water (Qadir and Scott, 2010). Increasing soil organic carbon may also lead to more salts being dissolved due to chelation and movement of the salts to lower layers in the soil (Chen et al., 2013b). The electrical conductivity of the soil solution can play an important role in controlling sodicity effects and it has been reported that its effects can be reduced with increased electrical conductivity of soil solution (Qadir and Schubert, 2002, Muyen et al., 2011).

Table 1 The effects of excessive concentrations of salts and major ions in wastewater used for irrigation

Implication	Compound	Effects	Comment	Reference
Soil	Salt accumulation in soil (TDS, EC)	Causing salinity problem (lateral drainage is increased, soil erodes more easily, oxygenation limited negative, the effect on microbiological activity, and loss of soil productive capacity and fertility).	Major problem in arid and semi-arid zones as evaporation rate would be higher and accumulated salt is not flushed regularly from the soil profile by rainfall	(Toze, 2006a, Leal et al., 2009, Muyen et al., 2011, Qadir and Scott, 2010, Malash et al., 2005, Hamilton et al., 2005, Qadir and Schubert, 2002, Rietz and Haynes, 2003, Friedel et al., 2000, Sou/Dakouré et al., 2013, García and Hernández, 1996)
	Excessive exchangeable sodium cation Na^+ concentrations related to magnesium and calcium(SAR), exchangeable sodium percentage (ESP)	Leads to sodicity problems which can cause deterioration of soil structure, clay dispersion with subsequent blocking of pores, negative effects of hydraulic properties such as causing soil impermeability		
	Excess level of carbonate and bicarbonate	Leads to elevated PH of the soil solution, dissolves Humus and sodium humate precipitates which give the black color for the black alkali soils.		
Plants	Excess salt (salinity) leading to changes in the osmotic pressure in the root zone,	Osmotic effects depress makes the water less available to the plants leading to plant stress and growth reduction		(Muyen et al., 2011, Mohammad and Mazahreh, 2003, Hamilton et al., 2005, Ayers and Westcot, 1985, Pedrero and Alarcon, 2009, Katerji et al., 2003, García and Hernández, 1996, Qadir and Schubert, 2002)
	Excessive exchangeable sodium cation Na^+ concentrations related to magnesium and calcium(SAR), exchangeable sodium percentage (ESP) (sodicity), Excess level of carbonate and bicarbonate (alkalinity)	Cause photo-toxicity, plants nutrients deficiency (e.g., phosphorus, potassium), and N losses due to NH_3^+volatilization, seedling emergence problems, plant root growth restriction and cropping difficulties		
	Excessive chloride, sodium, and boron	Specific ion toxicity		
Groundwater	Salts and ions leach each to groundwater	Water quality deterioration	TDS>500 Cause flavor but do not affect human health; High level of TDS can cause corrosion of water distribution equipment.	(Toze, 2006a, Yu et al., 2012, Kass et al., 2005, Hamilton et al., 2005, WHO, 2006)
Surface water	Salts and irons reach surface water via drainage systems or soil erosion	Water quality deterioration		

Very high concentration may limit its use

Boron which is not removed by treatment, absorbed by plants or wholly retained in the soil can be toxic. Accumulation in water bodies limits their use in agriculture

1.1.2. Salinity and sodicity management options:

Removing salts from wastewater for irrigation purposes is prohibitively expensive. Therefore, there is a need for specific measures and management strategies to prevent and control the effects of salinity and sodicity during irrigation with wastewater.

One important option for salinity control is regular application of effective leaching of water to transfer solutes through the soil profile and ensure the leaching of excess salt below the root zone (Carr, 2011, Maas and Grattan, 1999, Letey et al., 2011, Hillel, 2000). To achieve leaching requirements, an adequate soil drainage system is an essential prerequisite. This can be facilitated through natural drainage if the soil has sufficient storage capacity or permeable subsurface layers, or via artificial drainage systems. In addition to soil drainage, adequate groundwater depth and land levelling are also important components to control salinity in the root zone (Simmons et al., 2010).

Crop selection was found to be the principal factor for the sustainability of wastewater irrigation since certain crops can be irrigated with wastewater without any negative impact on yield. A number of field crops, fruit trees, forage grasses and others have been identified in the literature to suit various salt-affected environments (Simmons et al., 2010, Ayers and Westcot, 1985, Maas and Grattan, 1999, Grattan et al., 2004). As it was mentioned earlier, salt tolerance can be divided into four classes including those that are sensitive (Sesame, Carrot, Onion, Almond and apple), moderately sensitive (Corn, Peanut, Alfalfa, Tomato, Cucumber and Grape), moderately tolerant (Sorghum, Soybean, Wheat, Squash, Fig and Olive and tolerant (Barley, Cotton, Oat, Date palm and Currant) (Maas and Grattan, 1999). Crop choice will depend on soil conditions, water quality and climate. Suitable crops should also demonstrate the following characteristics: (i) high water and N demand, and tolerance to salinity; (ii) good potential end use; (iii) marketable (da Fonseca et al., 2007).

Another management option to mitigate the salinity impact of wastewater irrigation is the use of the wastewater in conjunction with fresh water, if available, via blending or alternating approaches which provide more flexibility to suit different situations (Ayers and Westcot, 1985, Malash et al., 2005, Yu et al., 2012). Different field studies have evaluated various aspects of these approaches and one study suggested that the optimum ratio of mixing fresh water to wastewater is between 2:1 and 1:2 for plant growth (Yu et al., 2012). Another study carried out by Malash et al. (2005) found that a mixed management strategy with a 60% fresh water 40% saline water ratio in combination with a drip irrigation system gave the highest values of yield and growth in tomato production. An alternating strategy of fresh and saline water can also provide many advantages including the ability to grow a broad range of crops, flexibility to use conventional irrigation methods and control of soil salinity in topsoil during seeding stage to a lower level over time.

Since most crops are sensitive during their seeding stage especially grains (Barley, Wheat and Rice) Sesbania, Cotton, tomato, Corn, and sugar beets (Hanson et al., 1999); it may be possible to reduce the effects of salinity by using modifications of planting practice to minimise salt accumulation around the seeds. This may include sowing near the bottom of the sloping sides of furrows; increased plant density (the seedling rate per unit area) which could compensate for reduced germination; and growing seedlings with fresh water (Minhas, 1996, Ayers and Westcot, 1985).

The application method could also directly affect the efficiency of water use and the way salts accumulate in the soil profile. Some methods are more suitable for use with saline water than others. Several parameters in relation to risk reduction could be used to choose the most suitable method including leaf damage, salt accumulation in the root zone, ability to maintain high soil water potential and ability to handle saline water without significant yield loss. Each irrigation method has a combination of impacts on these parameters, which should be considered before any attempt to improve salinity and sodicity control by changing the irrigation method is undertaken (Maas and Grattan, 1999, Hillel, 2000, Pescod, 1992). In the case of sodicity problems, soil treatment is a particularly useful option to mitigate the effect of soil sodicity. Mitigating the effect of excess sodium on soil and crops can be achieved through improving soil physical properties and infiltration rate by adding chemical amendments such as gypsum (Simmons et al., 2010, Ayers and Westcot, 1985, Hillel, 2000). Leaving plant residues or adding organic matter to the field can also enhance the physical and chemical condition of soils irrigated with sodic water (Simmons et al., 2010).

Where available, water with a high electrical conductivity and an adequate proportion of divalent cations (mainly calcium) could also be used to improve sodic and saline-sodic water without the need for a calcium-supplying amendment (Simmons et al., 2010)

1.2. Metalloids and heavy metals:

Typically, municipal wastewater has lower concentrations of inorganic chemicals compared to industrial effluents, and usually conventional treatment processes are capable of significantly reducing their concentration as most will accumulate in the sludge (bio-solid) (Hamilton et al., 2007, Chen et al., 2013a, Toze, 2006a).

In general, the risk from inorganic chemicals particularly heavy metals present in wastewater is higher when industrial wastewater is mixed with municipal wastewater, a common condition in developing countries where industrialisation is accelerating and mixed wastewater is used untreated or partially treated (WHO, 2006). Where industrial effluent is used the heavy metal concentration in plant tissues were reportedly higher than permissible limits even when water and soil samples comply with established safe standards (Chen et al., 2013b, Khan et al., 2008). Table 4 illustrates the main potential effects from heavy metals in irrigation with wastewater.

Many metals pose little hazard to humans through contamination of the food chain due to the fact that they pose significant photo-toxic effects in low concentrations which are not toxic to humans and therefore inhibit plant growth. Generally, cadmium is the major relevant heavy metal which presents a risk to human health due to its high mobility and also the fact that it is bio-available to plants at very low concentrations that are not photo-toxic but could pose a health risk to human (Hamilton et al., 2007, WHO, 2006, Chen et al., 2013c, Khan et al., 2013). Based on many studies carried out in Southeast Asian countries such as Pakistan, India, and China, where industrial effluent with sewage (diluted or untreated) is widely used for irrigation, found that cadmium followed by Lead were the major metals which pose a risk to health (Khan et al., 2013, Tiwari et al., 2011, Khan et al., 2008, Singh et al., 2010, Lu et al., 2014, Verma et al., 2015, Gupta et al., 2008). In most of these case studies the concentration of cadmium and lead exceeded the permissible limits for heavy metals in irrigation water, i.e. WHO/FAO standards 0.01 and 5.0 gm/L for Cd and Pb respectively (Khan et al., 2013, Tiwari et al., 2011, Verma et al., 2015, Gupta et al., 2008)

1.2.1. Factors influencing the impacts of heavy metals:

The magnitude of the risk from heavy metal in wastewater depends largely on the type of effluent. Typically, most domestic treated or partially treated wastewater has low levels of trace elements and usually within the permissible limits for irrigation water quality (Klay et al., 2010, Al Omron et al., 2012, Mohammad Rusan et al., 2007). Table 2 provide a summary of the average metal concentration in treated wastewater effluents used for irrigation in different countries. Many studies have estimated that domestic treated or partially treated wastewater can be used safely for up to a century without any negative effects to crops, groundwater or the food chain (Chen et al., 2013c, Smith et al., 1996, Tarchouna Gharbi et al., 2010).

Table 2 Average metal concentrations in treated wastewater effluents used for irrigation in different countries

Metal	Tunisia [1]	Jordan [2]	Spain [3]	Saudi Arabia [4]	RMC [a] [5]
Cd	0.005	0.02	0.03	0.0006	0.01
Co	0.019	-c	-	0.0005	0.05
Cr	0.016	-	0.02	0.037	0.1
Cu	0.017	0.01	0.02	0.014	0.2
Pb	0.044	0.77	0.02	0.0048	5
Zn	0.36	0.19	0.11	0.0055	2
Ni	0.034	-	0.12	0.0044	0.2
Mn	0.054	-	0.03	0.0055	0.2

a) RMC=Recommended maximum concentrations for crops production; b) not available; c) ND=not detected

Sources: 1.(Bahri, 1998)2(Mohammad Rusan et al., 2007)., 3(Pedrero and Alarcon, 2009) 4.(Al Omron et al., 2012) 5.(Pescod, 1992, WHO, 2006),

The major concern with regard to the potential effects of heavy metals on agricultural production and human health would be related to the use of untreated wastewater or the use of biosolids as fertilizers (Hamilton et al., 2007). Moreover, heavy metals would be a critical issue when industrial wastewater is used or blended with domestic wastewater and used for irrigation (Mapanda et al., 2005, Chen et al., 2013a, Toze, 2006a). Long-term reuse of wastewater containing industrial discharge leads to accumulation of heavy metals in both soil and plants (Liang et al., 2011).

The period over which the application of wastewater containing heavy metals takes place has also has an impact on the change of heavy metal concentrations irrigated soils. Many studies show that heavy metal accumulation starts to occur after 5 to 8 years of application (Xu et al., 2010, Rattan et al., 2005). The process of accumulation of metals in soils can take a long time (e.g. several decades to a century) before causing any negative effects to crops, groundwater or risks to human health. (Klay et al., 2010, Siebe and Fischer, 1996, Zhang et al., 2008). However, eventually, it may lead to increase the concentration of metals in soils to levels beyond soil capacity and subsequently increasing their mobility and plant uptake (Sridhara Chary et al., 2008, Friedel et al., 2000).

Another factor that could affect metal accumulation and plant uptake is soil properties since some soils have a high capacity to absorb and retain heavy metals. In such soils, wastewater with an average metals concentration may be applied to land for several decades without fully exhausting the soil capacity (Hamilton et al., 2007, da Fonseca et al., 2007). However, when the capacity of the soil to retain heavy metals is reduced as a result of continuous application of wastewater or a change in soil PH, the metals enter a mobile phase, and may be released to groundwater or to be available for plant uptake (Kumar Sharma et al., 2007, Mapanda et al., 2005)

Metal mobility and bioavailability in the soil will vary considerably with soil properties for similar total soil metal concentrations (Hamilton et al., 2007). Mobility and bioavailability is a function of the amount of organic matter, clay minerals such as montmorillonite in soils (Usman et al., 2005, Olaniran et al., 2013), $CaCO_3$ content (Avci and Deveci, 2013), and soil pH (WHO, 2006, Mapanda et al., 2005, Sridhara Chary et al., 2008, Friedel et al., 2000, Siebe and Fischer, 1996, Kiziloglul et al., 2007). It has been found that alkaline soils ($pH > 6.5$) or/and high levels of organic matter combined with clay contribute to decreasing the mobilisation of heavy metals consequently reducing their availability for plant uptake or leaching. Soil $CaCO_3$ has also been found to increase the retention capacity for metals in soils (Brar et al., 2000, Mapanda et al., 2005, Friedel et al., 2000, Siebe and Fischer, 1996).

Soil pH has great influence on mobility and bioavailability of heavy metals and in general metals are more available to plants from acidic soils than from neutral or alkaline soils (WHO2006). Soil pH changes depending on the pH of the irrigation water and consequently the application of wastewater with a low PH could lead to decreased soil pH and this in turn could cause an increase in the mobility of heavy metal which would then become available for plant uptake or leaching to lower soil layers (Xu et al., 2010)

Since soil organic matter has the capacity to form stable complexes with metal ions, it will affect their solubility and bioavailability in soils (da Fonseca et al., 2007, Klay et al., 2010). If the organic matter is in the solid form it will improve the heavy metal adsorption capacities of soils. However on the other hand, dissolved organic components enhance the solubility of metals thereby increasing their mobility and bioavailability particularly at low loading rates (Klay et al., 2010, Siebe and Fischer, 1996).

The rate at which heavy metals accumulate in plants depends on the plant species. The efficiency of metal absorption can be facilitated by either plant uptake or the soil-plant transfer factor of metals (Khan et al., 2008). Many studies have found that leafy vegetables such as spinach, mint, and coriander tend to accumulate more heavy metals in their edible parts compared to non-leafy vegetables such as root crops (carrot, garlic), grains (wheat and corn) and fruits (tomato) (Khan et al., 2013, Avci and Deveci, 2013, Ghosh et al., 2012, Simmons et al., 2010).

Furthermore, heavy metal concentrations in the different parts of the plant will also vary. Usually plants accumulate metals more readily in their roots compared to other parts of the plant such as the leaves, fruits, and seeds. As a result, the roots act as a barrier against heavy metals translocation. In general, heavy metal concentrations in different portions of plants follow the order of root>stem>leaves>fruits> seeds (Liang et al., 2011, Ghosh et al., 2012, Keser, 2013, Mireles et al., 2004). Table 3 provides heavy metals concentration in edible parts of some crops found in the literature.

Table 3 **Heavy metal concentrations (mg/kg dry weight) in the edible portions of food crops grown in wastewater-irrigated soil, and selected regulatory limits.**

Crops	Statistics	Cr	Ni	Pb	Cd	References
Coriander	Range	1.29-9.47 1.02-3.11	2.95-5.89 0.12-0.60	21.04 - 53.15 NA*	3.38-4.39 0.17-1.03	(Khan et al., 2013) (Ghosh et al., 2012)
Spinach	Range	3.30-7.75 0.11-0.35	3.79-5.05 0.35-1.79	19.19-25.10 NA	1.83-4.48 0.34-2.06	(Khan et al., 2013) (Ghosh et al., 2012)
Mint	Range	1.72-5.15 2.60-5.50	3.0-4.62 3.00-6.70	20.3-55.36 0.40-1.90	3.10-7.67 0.02-0.05	(Khan et al., 2013) (Avci and Deveci, 2013)
Onion	Range	1.29-5.59	3.79-7.16	33.59-52.78	3.48-3.93	(Khan et al., 2013)
Garlic	Range	2.15-3.01	3.36-6.73	24.36-33.39	2.29-3.48	(Khan et al., 2013)
Carrot	Range	0.86-5.59 0.34-1.04	2.95-6.31 0.24-1.19	23.99-31.00 NA	2.28-2.84 0.085-0.52	(Khan et al., 2013) (Ghosh et al., 2012)
Radish	Range	0.86-3.44 0.45-1.38	2.95-7.16 0.41-2.09	28.42-36.54 NA	2.47-3.02 0.24-1.44	(Khan et al., 2013) (Ghosh et al., 2012)
Okra	Range	1.29-5.59	2.53-5.89	23.99-47.61	1.74-2.38	(Khan et al., 2013)
Tomato	Range	0.86-2.15 1.02-3.11 2.00-4.20	3.37 -6.31 0.29-1.49 1.80-6.10	29.89-34.33 NA 0.10-0.70	1.83-2.75 0.085-0.52 0.02-0.53	(Khan et al., 2013) (Ghosh et al., 2012) (Avci and Deveci, 2013)
Eggplant	Range	2.60-5.50	0.6-2.70	0.30-4.50	0.01-0.34	(Avci and Deveci, 2013)
Wheat	Range	1.72-3.87	2.10-3.79	22.51-37.65	1.00-1.65	(Khan et al., 2013)
Corn	Range	2.00 - 3.40	0.60-3.50	0.20-3.50	<0.01	(Avci and Deveci, 2013)
FAO/WHO limits 2002	-	-	0.20	0.5-0.10	0.02-0.20	(Avci and Deveci, 2013)

*NA: not available

1.2.2. Heavy metal management options:

Although wastewater treatment is the best choice in managing wastewater in agriculture biological treatments are generally designed to remove organic compounds and microorganisms and therefore the removal of heavy metal by biological treatment may be regarded as a side benefit (Chipasa, 2003). The efficiency of metal removal by biological treatment processes will vary depending on the types of metals which are present and their concentration. Physical, chemical and biological factors will also affect the outcome, for example, heavy metal removal from activated sludge depends on pH and dissolved organic matter and an increase in pH will increase the removal as metals precipitate as hydroxides (Chipasa, 2003). High concentrations of heavy metals can be toxic to microorganisms and reduce microbial activity resulting in an adverse effect on biological treatment processes (Chipasa, 2003). In recent years, various treatment technologies for heavy metal removal from sewage, industrial and mining waste effluents have been extensively studied. These technologies include chemical precipitation, ion-exchange, adsorption, coagulation, cementation, electrochemical treatment technologies, membrane filtration and reverse osmosis (Fu and Wang, 2011). Each of these methods offers many advantages and also limitations for their use for the removal of heavy metals from wastewater. For instance, chemical precipitation has traditionally been used for metal removal from aqueous solutions due to its simplicity and low capital and operational costs, however, its efficiency can be affected by pH and the presence of another ions, it is also ineffective when metal concentration is very low (Fu and Wang, 2011, Baysal et al., 2013). Ion exchange, membrane filtration, and adsorption are alternative methods which have been wildly studied for heavy metal removal. Ion exchange has successfully been used to remove heavy metals from wastewater. Membrane filtration and adsorption have a high efficiency for the removal of heavy metals from wastewaters with low concentrations of heavy metal. However, these technologies have high capital and operational costs which limit their use especially on a large scale (Fu and Wang, 2011, Baysal et al., 2013).

The selection of the most suitable treatment method will depend on many factors including the metal concentration, other wastewater components, plant flexibility and reliability, capital investment and operational cost, and environmental impact.

Table 4 the effects of metalloids and heavy metals in irrigation with wastewater

Implication	compound	effects	Comment	
Soil	Aluminum and Iron	Aluminum blocks productivity in acid soils as a result of reducing nutrient mobility especially phosphorus Iron can contribute to acidification and reduce phosphorus mobility	In alkaline soils with pH >7 the impact of aluminum is negligible due to ion precipitation.	(Simmons et al., 2010, Mapanda et al., 2005, WHO, 2006, Zhang et al., 2008)
	High concentration of heavy metal	Depending on pH, organic matter and metals content, metal can bind to soil particles and accumulate or mobilize into groundwater Once accumulated in soil removal can be difficult. Contamination can endure for hundreds of years due to long biological half-life. Negative impact on soil microbial biomass, microbial structure, microbial diversity, and bacterial abundance after long-term exposure	Particularly in rapidly industrializing regions where industrial wastewater is mixed with domestic wastewater	
Plants:	Aluminum and iron	Could be toxic and also cause Phosphorus deficiencies depending on type of soil and pH,		(Hamilton et al., 2005, WHO, 2006)
	Arsenic, mercury, lead	As strongly adsorbed by soil only can be uptake by plant root but not translocation to shoots Generally phytotoxic at high concentration	Arsenic toxicity range from 12 mg/l to less than 0.05mg/l, mercury and lead not phytotoxic except at very high concentration,	(Sridhara Chary et al., 2008, Hamilton et al., 2005)
	copper, manganese, nickel, zinc	Less strongly adsorbed by soil, readily taken up by plants. Phytotoxic to plants at concentration before the concentration to be toxic to human. pose little risk to human health	Toxicity to plant reduce in neutral or alkaline PH, soil plants barrier protects food chain from these elements Copper could be harmful to animals at low concentration to visibly affect plants	(Hamilton et al., 2005, WHO, 2006, Sridhara Chary et al., 2008)
	Cadmium, cobalt, selenium, molybdenum	Bioaccumulation in plants tissue. Generally, not phytotoxic to plants and pose risk to animal and human health	Cobalt tends to be inactive in neutral and alkaline soils	(Hamilton et al., 2005, WHO, 2006)

Ground Water	Leach form acid soil and /or highly permeable and shallow water table conditions	Contaminate water and pose risk to human health if it used for drinking purpose.	Particularly cadmium, lead, and mercury	(Gwenzi and Munondo, 2008, WHO, 2006)
Surface water	If metals became mobile can reach surface water through runoff or drainage systems	Contaminate water and pose risk to aquatic life and can reach to human via food chine		

In the absence of treatment options to remove heavy metals from wastewater, other management measures at farm level could be very useful to reduce heavy metal transfer into the food chain. However, these measures may be more effective on soils with low or medium levels of contamination. Each of them has advantages and drawbacks and the effectiveness of using one or combinations of these measures will depend on the specific site conditions. One of the most effective options are plant-based treatment and soil based treatment

Plant based treatment includes growing of photo-remediation crops, growing industrial crops and selecting crops with low metals uptake. Certain plant species can be used to absorb and uptake trace elements from soil to above-ground biomass. These plants are known as hyper-accumulators and have the ability to accumulate high concentrations of metals up to 100 time greater compared to other non-accumulator plants grown in the same contaminated soil (Chaney et al., 2007). Currently, there are around 400 species categorized as hyper-accumulators of metals such as Thlaspi caerulescens, Thlaspi caerulescens, Aeolanthus biformifolius, and Alyxia rubricaulis (Cobbett, 2003, Chaney et al., 2007)

The cultivation of industrial plants including fibre plants (flax, cotton etc.) and energy crops (Salix trees and reed canary grass) has been considered as a valuable option for agricultural use in areas where soils are impacted by heavy metals (Puschenreiter et al., 2005). In addition to industrial plants, aromatic crops could be grown on heavy-metals enriched soil without causing any significant risk of metals transfer from soil to oil and alteration in essential oil composition (Lal et al., 2013).

Selecting crops with low metals uptake could also be a very useful option to reduce any potential health risks via the food chain. Some crops such as leafy vegetables accumulate certain metals in their edible parts in greater amounts than non-leafy crops. Metals usually accumulate in leaves and roots more so than in the seeds and fruits, suggesting that legumes such as peas, and grains may be more appropriate crops than vegetables such as cauliflower, lettuce, spinach and carrots where heavy metals are present. In addition, fodder crops may be preferred since they pose a lower risk to human health as the process of transfer of metals via the food chain will be longer (Puschenreiter et al., 2005, Simmons et al., 2010).

Soil amendment is another farm based measure that could mitigate against pant uptake of heavy metals. Soil amendment can be classified into organic and inorganic amendment. Organic amendments such as farmyard manure (FYM), compost, biosolids or biosolid compost could effectively decrease the mobility and bioavailability of heavy metals in soils as a result of its high content of organic matter and high concentrations of P and Fe (Puschenreiter et al., 2005, Bolan et al., 2003). Inorganic amendments such as gypsum, lime $CaCO_3$, synthetic zeolites, phosphate material, Mn and Fe oxides and clay minerals are very effective in reducing metal mobility and bioavailability due to pH effects and the introduction of additional binding sites for heavy metals (Chen et al., 2003, Brown et al., 2004, Oste et al., 2002, Puschenreiter et al., 2005, Hettiarachchi and Pierzynski, 2002). Many of these amendments are by-products of industrial activities which are available in large amounts and are relatively inexpensive (Puschenreiter et al., 2005).

1.3. Nutrients

Wastewater commonly contains high concentrations of nutrients in the form of nitrogen, phosphorus and potassium, although concentrations will vary significantly, depending on whether untreated, diluted or treated wastewater is used. Table 5 provides a summary of the typical nutrient concentration ranges in untreated wastewater and in treated effluent from secondary and advanced tertiary processes

Table 5 Typical nutrient concentration ranges in untreated and treated effluent

Constituent (mg/L)	Untreated Wastewater	Conventional activated sludge [a]	Activated sludge with BNR [b]	Activated sludge with BNR, microfiltration, and Reverse osmosis [c]
Total nitrogen	35-60	15-35	3-8	≤1
Ammonia –N	20-45	1-10	1-3	≤0.1
NO_3–N	0–trace	10-30	2-8	≤ 1
Total Phosphorus	4-15	4-10	1-2	≤0.5

a. Secondary treatment: activated sludge including a nitrification step
b. Tertiary treatment: activated sludge and biological nutrient removal of nitrogen and phosphorus
c. Tertiary treatment: activated sludge and biological nutrient removal combined with advanced treatment

Sources: (Sperling and de Lemos Chernicharo, 2005)and (Carey and Migliaccio, 2009)

Although the nutrient supply capacity is considered to be one of drivers for wastewater use in agriculture, nutrients contained in wastewater can reach levels which are excessive. This could result in possible negative effects of oversupply of nutrients especially nitrogen and phosphorus. Oversupply of nitrogen through irrigation with wastewater could lead to excessive vegetative growth, delay in maturity and reduced crop size and quality which will result in low economic yield (WHO, 2006, Hamilton et al., 2005, Qadir and Scott, 2010, Chen et al., 2013a) . Nitrate leaching is another concern associated with nitrogen in wastewater which may lead to contamination of groundwater causing health problems including methaemoglobinemia in neonates (WHO, 2006, Hamilton et al., 2005, da Fonseca et al., 2007, Gwenzi and Munondo, 2008, Knobeloch et al., 2000, Candela et al., 2007). Furthermore, excessive nitrogen and phosphorous in irrigation water may impact soil microbial communities, in particular the microbial activities associated with cycling these elements (Becerra-Castro et al., 2015). The excess of nutrients can disturb the autochthonous soil microbial communities, for example the accumulation of inorganic-N (NO_3-N and NH_4^+-N) in soils could affect the microbial catabolic activity, especially the biodegradation of recalcitrant carbon compounds that are present in soil (DeForest et al., 2004, Ramirez et al., 2012). Both N (in the form of NO_3-N) and P can reach surface water via drainage systems or soil erosion and cause eutrophication or toxicity in other habitats (Hamilton et al., 2005, WHO, 2006, Wu, 1999) . Table 6 illustrates the potential effects of excessive nutrients.

1.3.1. Nitrogen:

The amount of nitrogen taken up by the plant, leached to groundwater, or lost via soil erosion and volatilization depends on the nitrogen concentration in the effluent and the soil, the type of soil, crop demand, soil permeability, irrigation rate and the vulnerability of the aquifer. Nitrogen supplied via irrigation is removed primarily through nitrification and subsequent ready uptake by plants as ammonium NH_4^+-N and nitrate NO_3-N. However when they are applied in excessive amounts they can affect the quality of crops (Chen et al., 2013a).

The concentration of ammonium NH_4^+ in treated wastewater is normally greater than nitrate and it usually binds to soil particles and is not leached. However it can easily be converted to nitrate via nitrification by soil bacteria, Nitrates are highly dissolved in the soil solution and they can easily be moved through wastewater irrigated soils especially highly permeable soils (Qadir and Scott, 2010). When they are applied in levels in excess of plant requirements there may be a risk of leaching into groundwater (da Fonseca et al., 2007).

1.3.2. Phosphorus:

Normally wastewater contains low concentrations of phosphorus. Phosphorus is stable in soils and is therefore considered beneficial with no negative impacts on the environment. This is the case even if wastewater effluents with high concentrations of phosphorus are applied over long periods of time (WHO, 2006). However, because phosphorus accumulates at or near the soil surface over the time, it can reach surface water through soil erosion and runoff contributing to eutrophication. (WHO, 2006, Qadir and Scott, 2010, Wu, 1999)

1.3.3. Potassium:

Potassium is not bioavailable from the soil as it is bound to other compounds and therefore, it usually needs to be added to the soil as fertiliser. In general, wastewater contains low levels of potassium and normally this is not sufficient to meet crops requirement, Therefore the use of wastewater for irrigation does not usually pose any risk to the environment associated with the presence of potassium (Emongor and Ramolemana, 2004, WHO, 2006)

1.3.4. Nutrient management options:

Wastewater treatment plants typically provide various physical, chemical, and biological methods to improve effluent quality however nutrient removal from wastewater requires tertiary treatment and infrastructure that may be economically prohibitive (Carey and Migliaccio, 2009). An alternative approach that can also be used to remove excess nutrient from irrigation wastewater is to place on farm treatment options that work as effective sinks for nutrients such as the use of wetlands or duckweed ponds (Simmons et al., 2010, WHO, 2006, Qadir et al., 2015).

Excessive addition of nutrients particularly N could be avoided by selecting crops that can take advantage of high concentrations of nutrients such as fodder grass (Simmons et al., 2010) or utilising the practice of crop rotation to enable the removal of any excess nutrients (Hamilton et al., 2005). Hamilton et al. (2005) and Snow et al (1998,1999) claim that the risk of nitrate leaching to groundwater could be significantly reduced by appropriate matching of crops and plant production systems to climate and effluent characteristics. For instance, in arid zones high yielding crops with large concentrations of nitrogen in their biomass (such as leafy vegetable and fodder grass) are likely to be more effective than tree plantations for decreasing nitrate leaching (Simmons et al., 2010, Hamilton et al., 2005).

Similar to salinity over fertilisation from wastewater application could be reduced by using wastewater blended with fresh water or water with low nutrient concentrations. However, this option would only be possible when fresh water is available (Hamilton et al., 2005, Simmons et al., 2010, WHO, 2006, Qadir et al., 2015).

Table 6 The effects from nutrients contents in irrigation with wastewater

Implication	compound	Negative effects	Comment	References
Soil	Excessive level of nutrients	Disturbance of soil microbial communities, and Microbial catabolic activity		(DeForest et al., 2004, Ramirez et al., 2012)
Plants	Excessive level of nitrogen	Excessive vegetative growth Delay in maturity Reducing crop size and quality, Low economic yield	Forage being the main food for cattle can cause grass tetany caused by imbalance of nitrogen, potassium and magnesium in pasture grasses	(WHO, 2006, Hamilton et al., 2005, Qadir and Scott, 2010, Chen et al., 2013a)
	Excessive level of phosphorus	No effect		
Ground water	High level of nitrate (N-NO_3)	Leaching of N particularly NO_3 could lead to contaminate groundwater and causing health problems mainly methaemoglobinemia problems	Nitrogen stable in ground water and can accumulate because of the reduction of microbial activities caused by limited carbon sources.	(WHO, 2006, Hamilton et al., 2005, da Fonseca et al., 2007, Gwenzi and Munondo, 2008, Knobeloch et al., 2000)
Surface water	Excessive level of nitrogen and phosphorus	Eutrophication	Particularly in arid and semi-arid zones	(Hamilton et al., 2005, WHO, 2006, Wu, 1999, Carey and Migliaccio, 2009)

1.4. Toxic organic compounds and emerging contaminants

Wastewater contains a wide variety of toxic organic compounds including priority organic pollutants such as pesticides (DDT, 2,4-D, Aldrin), industrial compounds (phthalates PCBs, non –ionic detergents), disinfection by-products, synthetic and natural hormones, Pharmaceuticals and Personal Care Products (PPCPs) (WHO, 2006, Onesios et al., 2009, Bolong et al., 2009, Muñoz et al., 2009, Cizmas et al., 2015). Many of them can be difficult to detect due to the lack of suitable analysis techniques that are able to directly detect them in low concentrations, Furthermore, they vary considerably in their form and their mechanism of actions which makes the identification and evaluation of these compounds a unique challenge (Bolong et al., 2009). These toxic pollutants may have carcinogenic, teratogenic and mutagenic effects. In addition, many of them are Endocrine Disrupters Chemicals (EDCs) which means that they may interfere with hormone functions in animals and humans. (WHO, 2006, Qadir and Scott, 2010, Bolong et al., 2009, Cizmas et al., 2015, Wu et al., 2015). Although direct evidence of negative human health effects are still being debated (Bolong et al., 2009, WHO, 2006, Toze, 2006a, Onesios et al., 2009, Bergman et al., 2013), relationships have been identified between endocrine disruptors and increased incidences of endocrine-related cancers such as breast, ovarian, prostate, testicular and thyroid cancer (Cizmas et al., 2015, Bergman et al., 2013). Abnormalities, altered immune function and population disruption due to exposure to these pollutants have also been observed in birds, reptiles, mammals, amphibians and invertebrates (WHO, 2006, Colborn et al., 1993, Bergman et al., 2013) .

Many EDCs, and PPCPs could persist in the environment and may accumulate in irrigated soils or eventually reach surface water or groundwater leading to human exposure through drinking water (WHO, 2006, Chen et al., 2013a, Chen et al., 2011). From the data available in the literature, soil systems are better equipped than water courses for the degradation of many of these compounds, with mechanisms including microbial degradation or adsorption by soil organic matter (Qadir and Scott, 2010, Chen et al., 2011, Dalkmann et al., 2014, Qin et al., 2015). However, it is still possible that some of them such as PPCPS may be taken up by crops or transferred to the edible surface of crops as a result of irrigation with wastewater or soil that remains on the surface of crops after harvesting (WHO, 2006, Wu et al., 2015). Most of the studies on pant uptake of PPCPs were conducted in greenhouses or the laboratory and data on the accumulation of these chemicals in crops irrigated with wastewater under realistic conditions is limited (Wu et al., 2015). However, research findings reported to date would suggest that the potential for these substances to enter edible parts of crops was low under normal field conditions (Wu et al., 2015, Prosser and Sibley, 2015). The literature also suggested that their effects on the quality of crops could be negligible (Chen et al., 2011, Wu et al., 2015). The major concerns related to PPCPs are the potential development of antibiotic resistance in soil and water microorganisms as result of discharging antibiotics into the environment (Toze, 2006a, Chen et al., 2011, Cizmas et al., 2015). The potential environmental effects of these toxic pollutants as result of irrigation with wastewater is summarised in Table 7.

Currently, considerable uncertainty exists regarding the potential risks of PPCPs and their transformation products to agricultural and environmental health.(Qin et al., 2015, Bergman et al., 2013). Although the presence of these substances in the environment and their potential ecological effects are generally alarming, their concentration in water sources and other environmental receptors to date are very low (Qadir and Scott, 2010), in addition, many of these chemicals have potential short environmental half-lives (Toze, 2006a, Chen et al., 2011).

1.4.1. Management options:

Many of the EDCs and PCPs tend to be resistant to conventional and even advanced wastewater treatment (WHO, 2006, Bolong et al., 2009, Fang et al., 2012, Wang et al., 2005). Certainly existing wastewater treatment plants have not been designed for the removal of these pollutants and even if the best available treatment technology is adopted, only a part of a wide range of emerging contaminants can be removed especially by biological treatment (Luo et al., 2014). The reasons for this are numerous and include the fact that these pollutants have a wide range of chemical properties and their successful removal even in advanced treatment varies significantly (Bolong et al., 2009, Yan et al., 2010, Luo et al., 2014). Secondly, there is no existing regulation specifically targeted at wastewater or water treatment criteria for these range of compounds (Bolong et al., 2009, Fatta-Kassinos et al., 2011). Finally the possibility of the existence of other potential unknown chemicals-of-concern makes it difficult to estimate the removal of all these chemicals under all available treatment technologies or environmental conditions (Toze, 2006b, Bergman et al., 2013)

Due to the lack of current knowledge on the actual effects of these chemicals on humans and the environment (Bergman et al., 2013), the mitigation measures that could be applied to manage their risks are limited to pre-treatment or segregation of industrial discharges (WHO, 2006, Simmons et al., 2010), the promotion of more clean production in industries and education of society to use less toxic compounds (WHO, 2006, Simmons et al., 2010).

Table 7 The effects of toxic organic compounds and emerging contaminants in irrigation with wastewater

Implication	Negative effects	Comment	reference
Soil	Adsorbed by soil particles and organic matter may affect soils microorganism and microbial communities	Removal efficiencies are greater in soils reach in silt, clay and organic matter	(Qadir and Scott, 2010, Chen et al., 2011, WHO, 2006)
plants	Their large size and high molecular mass prevent them to be absorbed by plants Many can be uptake by plant soil or transferred to edible surface of crops via irrigation water or soil remain in the surface of crop	There are experimental studies indicate adverse effect on plants growth and biomass particularly by PPCPs There is lack of data related to human health effects through food-crop chain. Their effects on crops health assumed to be negligible	(Qadir and Scott, 2010, WHO, 2006,Chen et al., 2011,Wu et al. 2014)
Ground water	Could reach to ground water under highly permeable and shallow water table conditions or leach from poor organic matter soil, which lead to Groundwater contamination and they may contribute to adverse effect to human health if reach drinking water sources		(Chen et al., 2013a, Chen et al., 2011, WHO, 2006)
Surface water	Can reach to surface water via runoff and affect aquatic ecosystems		(Toze, 2006a, Chen et al., 2011, Qadir and Scott, 2010, Bolong et al., 2009, Muñoz et al., 2009)

1.5. Organic matter and suspended solids:

Wastewater application will increase the organic matter content in soils, which may be considered a beneficial impact. Adding organic matter to soil through wastewater addition improves soil structure and moisture, enhances cation exchange capacity, helps to retain metals and reduce their mobility and bioavailability and adds more nutrients to soils (WHO, 2006, Qadir and Scott, 2010, Chen et al., 2010b). However, high concentrations of organic matter and suspended solids can have an adverse impact on soil porosity and favour anaerobic conditions in the root zone. In addition, if agricultural runoff contains high concentrations of organic matter and this reaches surface water, this may lead to depletion of dissolved oxygen in the water, resulting in hypoxic conditions and increasing the mortality of aquatic species (WHO, 2006, Qadir and Scott, 2010). High concentrations of organic matter and suspended solids may also lead to plugging problems in micro irrigation systems such as sprinklers and drippers (Qadir and Scott, 2010)

1.5.1. Management options:

Reducing the effect of high concentrations of organic matter and suspended solids can primarily be achieved by enhanced removal of suspended solids and organic matter by pre-treatment, Ploughing soils when they are clogged and allowing soils to biodegrade organic matter by reducing the application frequency may also mitigate the potential effects (WHO, 2006).

Ranking the risks from chemical components of irrigation with wastewater on arid and semi- arid zones

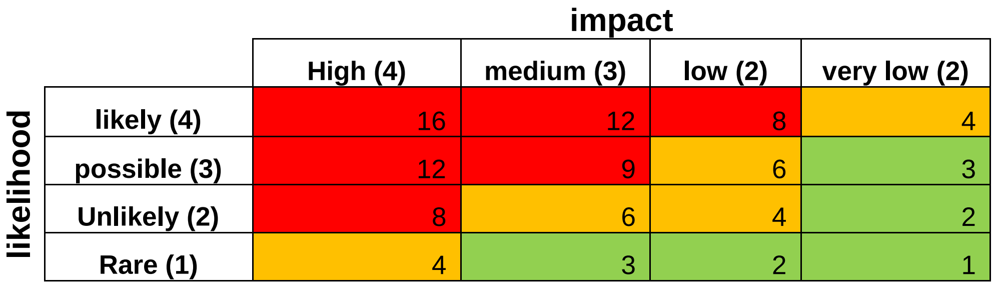
Based on the outcome of the literature review presented above an assessment was carried out to determine the relative environmental risk assessment associated with the use of wastewater contaminated with a range of chemical pollutants in arid and semi-arid zones. The key element for any valid risk assessment is to provide procedures for determining appropriate consequences (the impacts) and the likelihood (the probability of the hazard been realised) of each set of contaminants under a range of environmental conditions as result of irrigation with wastewater. For qualitative assessment, adequate descriptions for each level of consequences and likelihood is required. Based on standards (standards Australia, 2004a, 2004b) each of the sets has four levels of impact ranging from very low (no obvious and direct impact with a score of 1) to high (irreversible with a score of 3), with medium (a score of 2). The qualitative likelihood (Table 8) also has four levels ranging from Rare (Lack of evidence but not impossible with a score of 1) to likely (expected to occur; with a score of 4). The Risk value for each set was calculated based on a formal judgement on the consequence and probability using the mathematical formal of:

Risk = impact level x Likelihood level

A simple risk matrix adopted from was used to evaluate the significance of the risk as illustrated in Figure **1** where risk value of 1-3 (green) are typically perceived as low risks and it can be accepted, while risk values of 8-16 (red) are perceived as high risks and should be unacceptable and it is important to manage these risks. Table 9 and Table 10 summarise the results of the evaluation.

Table 8 Likelihood definitions derived from standards (standards Australia, 2004a, 2004b)

Level	Score	Descriptor
Likely	4	It is expected to occur
Possible	3	May occur sometimes
Unlikely	2	Uncommon but has been known to occur
Rare	1	Lake of evidence but not impossible



		impact			
		High (4)	medium (3)	low (2)	very low (2)
likelihood	likely (4)	16	12	8	4
	possible (3)	12	9	6	3
	Unlikely (2)	8	6	4	2
	Rare (1)	4	3	2	1

Figure 1 the method for assessing the environmental risks of irrigation with wastewater

The analysis shows that in arid and semi-arid zones where surface water and rainfall are limited the most significant environmental issue with respect to irrigation with wastewater would be salinity and sodicity. As a result of the high evaporation rate and the lack of rainfall, excessive salts are not naturally flushed out and accumulate in the soil profile causing soil salinity and/or sodicity leading to serious environmental problems that contribute to a loss of soil productivity and fertility, and potential yield losses.

Excessive nitrogen supply can also be an important concern. Managing appropriate levels of nitrogen could be a challenging task particularly in developing countries where most irrigation rates are designed to match water requirements rather than nutrient requirements, and oversupply of nitrogen may greatly affect the quality of crops and consequently reduce economic yields. Groundwater contamination from excessive levels of nitrate is a further area of concern.

Heavy metals present health risks since their impact on the environment and agricultural productivity is long term (from a few decades to a century depending on the type of effluent used). Health impacts associated with their transmission into the food chain are likely to arise long before they have a negative effect on the environment.

The potential adverse impact of exposure to emerging chemicals particularly EDCs have mainly been reported in aquatic environments (Qadir and Scott, 2010, Bolong et al., 2009, Toze, 2006a, Muñoz et al., 2009) and animals in direct contact with polluted water (mainly surface water)(WHO, 2006, Toze, 2006a). Whilst the risks associated with emerging contaminants in treated wastewater used for irrigation are still controversial and not fully known, some studies have claimed that these contaminants are unlikely to pose a serious threat to groundwater, soil environments or human health as a result of its agricultural application (Chen et al., 2013a, Chen et al., 2011, WHO, 2006, Wu et al., 2014, Wu et al., 2015). Nevertheless, there is a significant lack of studies concerning the prevalence and fate of emerging contaminants as a result of reusing wastewater for irrigation in terms of their potentially adverse effects on the terrestrial ecosystem, crop uptake and potential health impacts through the food-chain (Qadir and Scott, 2010, Muñoz et al., 2009, Chen et al., 2011, Fatta-Kassinos et al., 2011, Qin et al., 2015, Prosser and Sibley, 2015).

Table 9 Assessing the likelihood and the impacts and of chemical pollutants in irrigation with wastewater on related environments:

Hazards	**soil**		**plants**		**Groundwater**		**Surface water**		**health**	
	Likelihood	Impact	Likelihood	Impact	Likelihood	Impact	Likelihood	Impact	Likelihood	Impact
Salinity	Likely	high	likely	high	possible	medium	unlikely	low	unlikely	low
Excessive Nutrient										
• **nitrogen**	possible	low	possible	high	possible	high	possible	high	possible	high
• **Phosphorous**	possible	low	possible	low	unlikely	low	possible	high	rare	Very low
Heavy Metal	possible	high	possible	medium	possible	medium	unlikely	low	possible	high
Toxic organic compounds and emerging contaminants	possible	low	possible	low	unlikely	Very low	unlikely	high	unlikely	low
Organic matter & suspended solid	possible	low	unlikely	Very low	unlikely	Very low	unlikely	medium	rare	Very low

Table 10 Rank of the risks from wastewater reuse in agriculture

hazards	score of the risk from irrigation with wastewater				
	soil	plants	Groundwater	Surface water	health
Salinity and sodicity	16	16	9	4	4
Excessive Nitrogen	6	12	12	12	12
Excessive phosphorous	6	6	4	12	1
Heavy Metal	12	9	6	4	12
Toxic organic compounds and emerging contaminants	6	6	2	8	4
Organic matter & suspended solid	6	2	2	6	1

Conclusion:

Wastewater availability and its nutrient properties make it a valuable alternative water supply for irrigation practice in arid and semi-arid zones. However, inappropriate management of irrigation with wastewater can contribute to serious environmental and health problems. This review was conducted in order to provide a comprehensive overview of the environmental and health risks associated with the chemical components of irrigation with wastewater aiming to evaluate and rank the risks from these constituents particularly on arid and semi-arid zones. Based on this review it can be concluded that salinity and sodicity followed by excessive nitrogen supply are the most significant environmental risks from irrigation with wastewater in arid and semi-arid zones where surface water and rainfall are scarce while heavy metals could be considered as a potential health risk more than an environmental concern. Although there is a substantial range of literature dealing with the environmental and health risks from heavy metals as a result of irrigation with wastewater, more intensive studies are required on the effects of heavy metals on plant nutritional components. There remains a lack of studies that evaluate and quantify the environmental risks associated with PPCPs and emergent contaminants on terrestrial ecosystems due to wastewater and biosolids reuse in agriculture. In addition, further research is needed to understate the influence of soils properties and plant factors on the uptake and translocation of PPCPs and emergent contaminates in plants. The health risks of the exposure to mixture of PPCPs via food crop chain as a result of irrigation with wastewater requires more investigation.

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