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Review

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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1. 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

2. 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 depend 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.

2.1. 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,