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Framework to assess sources controlling soil salinity resulting from irrigation using recycled water: an application of Bayesian Belief Network

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A B S T R A C T

Past literature suggests that the irrigation using recycled water over long period of time can lead to accumulation of salt in the soil. In this study, an assessment framework is proposed to evaluate the salinity sources that can have significant impact on the vadose zone salinity when recycled water is used for irrigating sporting ovals. The framework is constructed with a probabilistic expert system, namely, Bayesian Belief Network (BBN). The BBN model analyses the exposure pathways of salt arising from households to its final destination, i.e., accumulation in the soil via the recycled water irrigation. The salt transport modelling indicated a general trend of increase in both total dissolved solids (TDS) and Na^+ concentration in the root zone for a simulation period of 1277 days. The BBN analyses indicated that the wastewater stream from washing machines was the major salt source influencing soil salinity, closely followed by the wastewater stream from toilets. Results show that by reducing TDS load by 50% from washing machine alone, reduces the TDS concentration in soil by about 9% and this can be increased to 19% by reducing the TDS loads from both washing machine and toilet water, simultaneously. The study highlighted that any strategies that help in the reduction of salt in the wastewater stream from washing machine will be beneficial in managing the soil salinity as a result of recycled water use for irrigation. Thus, the proposed framework can help to develop recycled water irrigation schemes which are sustainable over the long-run.

1. Introduction

Recycling is one of the viable options to attain sustainable management of wastewater. The merits of recycled water is diverse which include reducing pressure on existing fresh water supplies, minimising effluent disposal to surface or coastal waters and provisioning constant volume of water than rainfall-dependant sources (Chen et al., 2012). The supply and use of recycled water may play an important role in enhancing urban water supplies in many water-scarce parts of industrialized countries because of its reduced treatment cost relative to seawater desalination and imported surface water. Stokes and Hovarth (2006) stated that the specific energy needs of supplying recycled water (1.8 kWh/m^3) is relatively the lowest compared to seawater desalination (3–4 kWh/m^3) and imported surface water (2–3.2 kWh/m^3) for a water scarce region in Southern California. The technological improvement and economic affordability of wastewater treatment has made wastewater recycling a reality and broadened the most sustainable use of recycled water. One such reuse option includes application of recycled water in sports fields and public open spaces. In Sydney, Australia, recycled water has been used for irrigation since 1960s. In 2011, Sydney Water supplied about 3.8 billion litres of recycled water for irrigating farms, sports fields, golf courses, parks, landscapes and racecourses and by 2015, it is expected that the recycling water will meet 12% of total water demand in greater Sydney (Sydney Water, 2013). Also, by 2015, Melbourne (another major city in Australia) is expected to achieve recycling of 23% of urban effluent and the national target for recycling water is set at 30% by the Australian Government (Lane and Ward, 2010). Thus the increasing use of recycled water, particularly for irrigating sporting and open fields, in the place of fresh water is one of the important goals of the local and national governments to achieve sustainable

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management of water. A green and sustainable sporting field provides a range of direct and indirect social benefits. Sporting facilities give a sense of social place, allow one to gain social recognition, allow one to teach and lead others, and in general allow users to feel free and independent in a natural environment than in a traditional home or work environment (Maheshwari, 2011). Hence, recycling wastewater meets the triple bottom line, namely, social, environmental and economic objectives.

However, the downside of using recycled water, particularly for irrigation, is due to its contaminants. Sewage from domestic sources contains several contaminants including detergents, floor cleaners, medicines, toothpaste, chlorine bleaches, hand lotions, mouthwash, shampoo, cosmetics, disinfectants, hair-dyes and tints, skin ointment, shaving cream and general cleaners (Munoz, 1994). Particular contaminant that is of concern for this study is salts. The main contributors to salinity from the domestic sources are sodium based detergents and other chemicals used in washing clothes and utensils, and sodium based salts used in food preparation (Patterson, 2004; Stevens et al., 2011). In a typical household, major appliance which contribute salt load to the grey water include dishwasher, washing machine, shower, kitchen and bathroom sink. In general, the salt along with other household waste (faeces, paper and food scraps) is discharged into sewer system and finally to the sewage treatment plant (Patterson, 2004). While most organic matter is removed by various wastewater treatment processes, the majority of mineral salts pass through the wastewater treatment system unaffected, unless reverse osmosis is used as one of the treatment processes (Rebhun, 2004). As such, the recycled water contains elevated levels of salt (Rahman et al., 2012), when the recycled water is used for irrigation, there is a potential risk of salt increase in the vadose zone. According to Food and Agriculture Organization (FAO), irrigation water has no impact on the growth of crop if the TDS is below 0.45 g/L, medium impact if the TDS is between 0.45 and 2.0 g/L and high impact if the TDS is more than 2.0 g/L (Ayers and Westcot, 1985). As per these guidelines, the recycled water considered in this study will come under medium impact irrigation water.

Several studies have reported increased salinity due to the prolonged use of recycled water for irrigation. Distinct long-term effects of recycled water use in terms of salinity have been observed in agricultural field (Dikinya and Areola, 2010). They observed that after three years of irrigation with recycled water, the electrical conductivity (EC) in soil increased from 105 to 235 μS/cm and Na^+ concentration increased from 2.95 to 5.75 meq/100 g of soil. Jahantigh (2008) reported 95% increase of salinity levels for a field which used recycled water for irrigation over five years. Increase of salinity in terms of EC, Na^+ and Cl^- are also reported in a number of other studies (Xu et al., 2010; Klay et al., 2010; Adrover et al., 2012; Candela et al., 2007).

Higher salt levels in the soil can adversely affect the soil potential for supporting plants and crops growth (Grewal and Maheshwari, 2013; Bernstein, 1975; Al-Hamaideh and Bino, 2010). Hence, it is important to control the salt accumulation in the soil, particularly in the root zone, by controlling the salt levels in the irrigation water. Effective source control measures can help reduce salinity in the recycled water and hence in the soil root zone.

Source control includes the identification and monitoring of contaminants, with a view to reduce or eliminate these, before entering the sewer system. This is critical in order to protect the sewage collection infrastructure, workers at sewerage systems, efficiency of treatment processes, effluent quality, and the receiving environment. In addition, source management, in particular, is becoming important in the context of sustainable management of resources, as the potential pollutants are prevented from entering into the environment. Similarly, source control in the case of controlling the salt in the wastewater can yield more sustainable use of recycled water for irrigation purposes.

None of the previous studies, mentioned above, considered the contributing sources of the salinity in managing salinity and, hence, achieve sustained irrigation over the long run. In this study, a novel methodology incorporating Bayesian Belief Network (BBN) is proposed to identify the sources that significantly influence the soil salinity and sodicity within the context of using recycled water for irrigation. Bayesian Belief Network was applied in this study because this method can address multi nodal problem where one can determine the conditions at the source for the desired final effect. The BBN is capable of incorporating uncertainty of associated variables by using marginal probability distributions. The network provides graphical representation of key factors, which portrays a better understanding of the inter-dependent relationships between the factors of the decision process (Jensen and Nielsen, 2007).

Bayesian Belief Networks have been used successfully to better understand and model different environmental problems, which includes decision making on maintaining ecological health of river, framework to maintain sustainability of coastal lake-catchment system, and assessing sources of salinity in coastal aquifer (Chan et al., 2012; Ticehurst et al., 2007; Ghabayen et al., 2006). In the case of recycled water, Bayesian belief network was used mainly for assessing health risk (Donald et al., 2009, 2011). In addressing the health risk from recycled water, Quantitative Microbial Risk Assessment (QMRA) models were widely used by many researchers (Donald et al., 2011; O'toole et al., 2009 and Zaneti et al., 2012). Although QMRA is considered as an essential component of microbial risk assessment of recycled water scheme, the model has some cons; it is tedious and technically demanding. This disadvantage was overcome by another model named Recycled Water Irrigation Risk Assessment (RIRA), which is useful for water resource and public health professional to conduct QMRAs for recycled water irrigation (Hamilton et al., 2007). However, RIRA is a deterministic model, which has limitation to take into account the uncertainty associated with the parameters. Donald et al. (2011) incorporated uncertainty of parameters in QMRA by Bayesian belief approach, which eliminated possibility of taking erroneous decisions for public health and risk management. Most of the studies discussed above applied Bayesian Belief Network for analysing recycled water from microbial point of view, which emphasized the human health risk from recycled water. But the application of Bayesian Belief Network for managing salinity issues associated with the use of recycled water for urban irrigation has not been reported. Therefore, the proposed decision support system (assessment framework) incorporating Bayesian Belief Network is a novel technique. The main objectives of the present study are (i) to use a probabilistic method, viz., Bayesian Belief Network, to evaluate the risk of salinity hazard associated with the use of recycled water for irrigation; (ii) to assess the influence of salt loads at the source on the salt accumulation in the soil of the sporting oval considered in this case study; and (iii) to identify the salt sources that have maximum influence on the salt accumulation in the soil.

2. Case study area

The Greygums oval (33^0 43.652′S, 150^0 42.406′E) is situated in Cranebrook, New South Wales, Australia (Fig. 1). The oval is used for athletics during summer season and Australian Rules football during the winter season. This oval is irrigated by sprinkler method using the recycled water from a domestic sewage treatment plant (Penrith Sewage Treatment Plant) since January 2008. The recycled water used for irrigation is stored in a 25,000 L concrete tank and up to 553 kL/day of recycled water is used for irrigation of the oval.