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# **Urban wastewater reuse for irrigated agriculture in Jordan: Soil sustainability, perceptions and management**

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## **Abstract**

Jordan is a country with very limited water resources and urban treated domestic wastewater offers a valuable contribution to the country's water balance. Water reuse is particularly well-suited to irrigated agriculture, for which water is in constant demand. The physical characteristics of the water (high organic content and solute loaded) mean that suitable soil management strategies, such as periodic leaching and nutrient management are required to maintain soil productivity and prevent the accumulation of plant toxic solutes. The effect of water reuse on soil sustainability was investigated by means of soil sampling and analysis combined with interviews with farmers and organisations involved with water reuse. The results reveal that the perception and knowledge of the water is important in the process of decision-making as to the relevant management strategy to be applied. The research stresses that maintaining soil sustainability when reusing water is imperative for agricultural development in Jordan and is achievable through water management both on and off the farm.

## **Keywords**

Perception; sustainable development; urban water; water management; water re-use

## **INTRODUCTION**

Water scarcity is a growing problem across the world as greater pressure is placed on the available water resources. Rising populations require more freshwater for drinking, domestic uses and particularly for food production. Irrigated agriculture is essential to sustain the increasing populations and in arid and semi-arid lands it commonly absorbs a majority share of the freshwater resources. The countries of the Middle East are facing some of the greatest water shortage problems in the world. The available resources are significantly lower than the potential demands placed on them by industry, agriculture, tourism and domestic uses. Jordan, at the centre of the Middle East, is one of the most water scarce countries of the world. With only 497 cubic metres per person per year (FAO Aquastats, 2008) it is well below the official criteria for water scarcity of 1000 cubic metres per person per year (Winpenny, 2000).

There are three principal ways which water scarcity can be alleviated. Firstly, through the development of new resources via the construction of dams, desalination of sea water or by exploiting deep groundwater resources. Such schemes typically involve hard engineering and technological developments and tend to be expensive. Secondly, the aim may be achieved through water demand management which aims to lower the demand for water by encouraging water saving devices and reducing water use in the home, in industry and in agriculture. The third approach is by reusing urban domestic wastewater after it has been treated. Treated wastewater is particularly well suited for agriculture as it often contains significant quantities of plant essential nutrients like

nitrogen, phosphorus and potassium. The strong psychological aversion to reallocating used water to domestic needs also drives the use of treated wastewater for irrigated agriculture.

In Jordan water reuse is taking place on a grand scale. 65 per cent of households are connected to a central sewage system (Water Authority of Jordan, 2007) which means that about 80 million cubic metres (MCM) of wastewater are produced annually (Vallentin, 2006). This constitutes just under 10 per cent of Jordan's 850 MCM of renewable water annually. The majority of this is produced at the Khirbet As Samra treatment plant located 30 km east of Amman (the capital of Jordan). Figure 1 is a schematic diagram showing the domestic to waste to irrigation water pathways in north-west Jordan. It shows that the majority of the wastewater coming from Amman is sent to the Khirbet As Samra treatment plant. After treatment the water is released to the Zarqa River, where it flows down to the King Talal Reservoir. From the reservoir it is then released as required to be used for irrigation in the Jordan Valley (a major agricultural area). The use of the water is split between that consumed directly around the treatment plant and that used indirectly (after significant transportation and the seasonal addition of natural surface runoff) in the Jordan Valley.

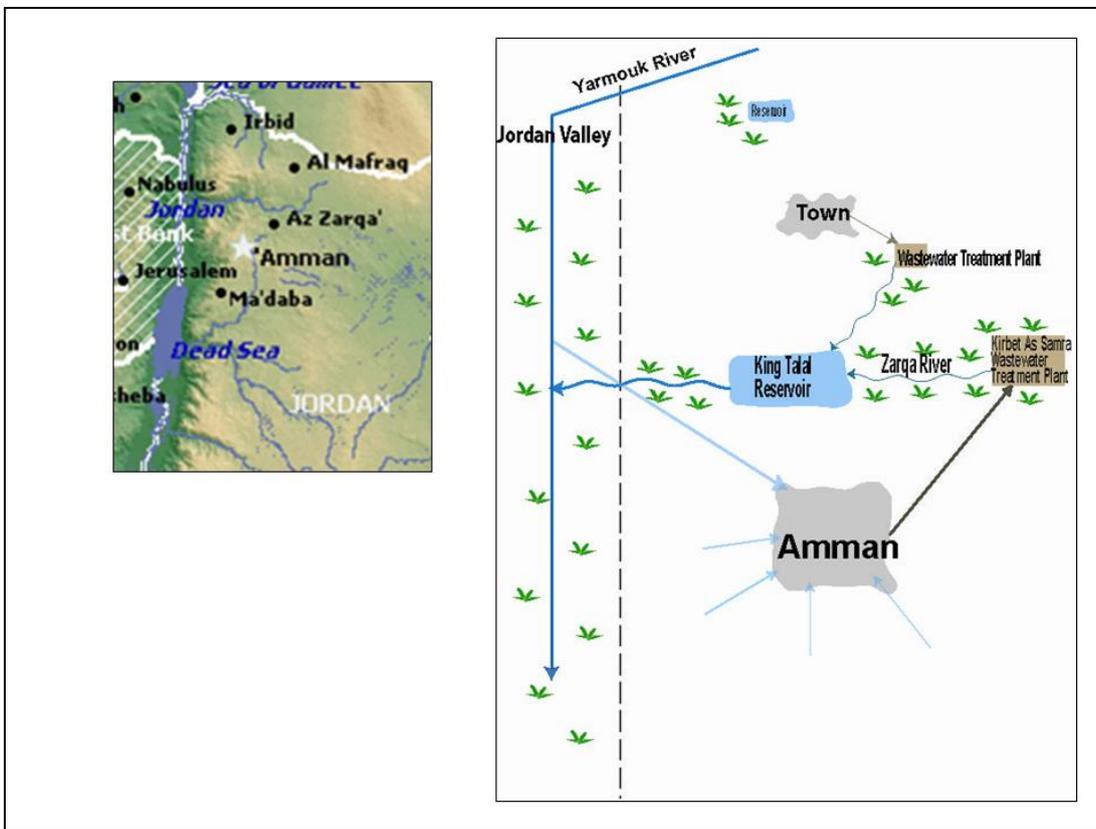


Figure 1 Schematic diagram and corresponding map of the water pathways in north-west Jordan

Water has been reused successfully in Jordan for several decades and the aim of this research is to investigate the sustainability of this practice in terms of both the effects on soil and the ability of people to manage and mitigate these effects. Water management is increasingly emphasising the importance of an holistic and interdisciplinary approach to overcome the water challenges of the 21<sup>st</sup> century. The need to incorporate social considerations alongside technical planning is frequently discussed, yet in reality it is often limited or lacking. This research seeks to emphasise that combining approaches from the social and physical sciences is potentially rewarding in terms of findings for water management issues.

## **METHODS**

To reflect the interdisciplinary nature of the work, several different research methodologies have been utilised. These included soil sampling and laboratory analysis, mathematical modelling to further understand the processes affecting the soil and semi-structured interviews with stakeholders involved with water reuse.

### **Soil and water sampling and analysis**

In this work it was hypothesised that soil irrigated with treated wastewater would have a greater quantity of ions such as sodium ( $\text{Na}^+$ ), chloride ( $\text{Cl}^-$ ) and boron ( $\text{B}^+$ ) which are plant toxic in high quantities. These solutes enter the water through the use of domestic cleaning products in which NaCl and B are often present (Patterson, 2001; Reuben, 2004; Reuben, 1965). The limited availability of domestic water in Jordan leads to high concentrations of solutes which are not removed by standard treatment methods, and so when applied to the soil with the irrigation water over time, they can accumulate. Accumulation leading to soil salinisation is of particular concern in arid and semi-arid regions because the high rates of evapo-transpiration require large quantities of water to be applied to meet the crop water demand. The water is used by the plants or evaporated from the soil surface resulting in large quantities of salts becoming deposited in the soil. The accumulating ions can only be removed through the application of excessive quantities of water and the subsequent dissolution and transportation of the salts down through the soil profile. The accumulation of salts in the plant root zone jeopardises plant health and productivity and it may reduce the quality of the soil structure and lead to reduced soil fertility. The careful management of saline waters is required to prevent high levels of salts accumulating which threaten the sustainability of the soil system.

Soil sampling was conducted at several localities in Jordan to compare sites with higher and lower precipitation rates, with different qualities and quantities of irrigation water and with the application of management methods such as leaching. Soils were sampled from a number of depths in the soil profile down to 50 cm. Water samples were also collected at the same localities as the soil sampling in order to compile corresponding data on water quality.

Analyses were conducted to determine the salinity and pH of the soil through saturating a known quantity of soil with ultra-pure water and then removing this water by suction following the method suggested by Rowell (1994). The removed liquid (the soil saturation paste extract) could then be analysed to determine the overall salinity (electrical conductivity) of the extract (ECe), the pH, the quantity of major cations (e.g. sodium, potassium, calcium, magnesium and boron) using ICP-AES, and the quantity of anions (e.g. chloride, bicarbonate, phosphate, sulphate) using ion chromatography. The EC and pH of the water samples were measured in the field using hand held instruments and sub-samples were also collected for analysis using ICP-AES and ion chromatography.

### **Mathematical modelling**

Modelling soil salinity changes through the use of treated wastewater offers a way to determine the sustainability of agriculture. The Hydrus model (Šimůnek et al, 2005) is currently being applied to identify long-term salinity changes, leaching water requirements and therefore determine the overall water requirement for maintaining soil productivity.

### **Semi-structured interviews**

Extensive semi-structured interviews were conducted with 56 farmers and 29 organisations who work with treated wastewater. The aims of the farmer interviews were to gauge the perceptions of the water, to identify perceived and real problems and benefits and to document local knowledge of

how the water is managed to minimise adverse effects on crops and soil. To investigate the differences in perception and management between farmers reusing the water close to the treatment plants and those using it indirectly in the Jordan Valley time was spent interviewing farmers in three different locations. These were the Jordan Valley, around Khirbet As Samra wastewater treatment plant and around Ramtha wastewater treatment plant (in the northern highlands). At each locality a variety of farmers were selected with an even distribution of those managing large farms with access to secure export markets through to those cultivating small holdings producing crops for the local market. The interviews were conducted in the field via a translator with advanced knowledge of Jordanian agricultural systems. Notes were taken during the interviews and often a tour of the farm was given to clarify and explain management methods and issues. The interview notes were typed up and expanded according to memory immediately after the interviews. Each data bit (piece of information) within the interview transcript was then coded and grouped according to its code. This method meant that similarities and discrepancies between the farmers' views became clear and factors that were frequently mentioned or ignored became highlighted (Kitchin and Tate, 1999).

The organisation interviews were held with individuals working actively in the field of water reuse in the private sector, governmental, non-governmental and research institutions in Jordan. These interviews focussed on the perception of wastewater, but also covered wider management and implementation challenges, priorities for future research and management directions. These interviews were conducted in English and were either recorded or notes were taken during the interview. They were transcribed immediately after the interview with additional observations and comments. For analysis they were coded according to various themes and the coded data were analysed to identify similarities and differences between the individuals and the organisational groups. Quotes were identified for each theme and compiled together in order that narratives could be developed on water reuse from the perspective of the organisations.

## **RESULTS**

### **Water quality**

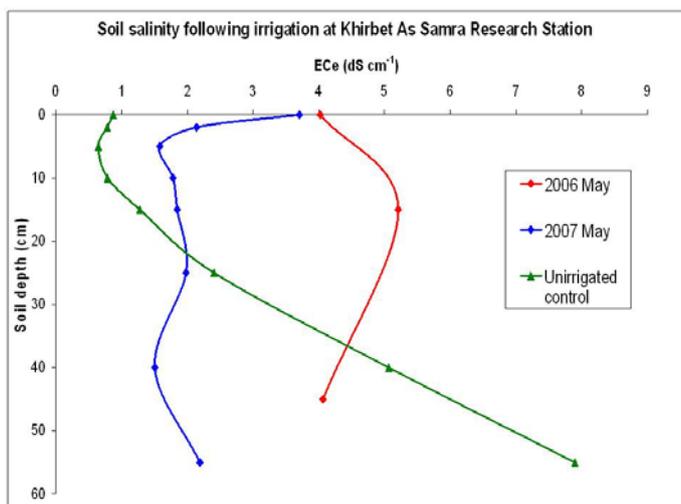
Table 1 shows the composition of water samples collected in 2006 and 2007 from the Khirbet As Samra research station. The electrical conductivity (EC) is used as a measure of salinity and the treated effluent in Jordan typically has an EC of  $2 \text{ dS m}^{-1}$ , which guidelines suggest gives the water a slight to moderate restriction to use (Ayers and Westcott, 1985). Of greater concern is the concentration of chloride in the water, which can reach  $400 \text{ mg l}^{-1}$  and which exceeds a recommended maximum concentration of  $350 \text{ mg l}^{-1}$  (Ayers and Westcott, 1985).

**TABLE 1: Selected parameters of the water samples from Khirbet As Samra and the Jordan Valley**

Location	Month and year of sampling	Solutes detected in the water (mg l <sup>-1</sup> )			Additional Parameters			
		Chloride (Cl)	Sodium (Na)	Boron (B)	Electrical Conductivity (EC) dS m <sup>-1</sup>	pH	Sodium Adsorption Ration (SAR)	Total Organic Carbon (TOC) ppm
Khirbet As Samra	Nov 2006	440.05	253.30	1.03	2.04	8.12	4.87	n/a
Khirbet As Samra	May 2007	174.25	265.31	0.84	1.68	7.83	5.83	10.97
Jordan Valley - Deir Alla	May 2007	299.54	173.21	0.55	2.09	7.50	3.45	9.45

### Soil sustainability

Results from sites irrigated with reclaimed water for known lengths of time reveal that salts do accumulate from water reuse. Figure 2 shows salinity data from an experimental site irrigated with known quantities and qualities of water for two consecutive years. The data show that after one year of irrigation the salinity of the soil increased dramatically relative to an un-irrigated control. However, at the end of the second season the salinity dropped. This is probably a result of the greater number of higher magnitude rainfall events in the second year which contributed more freshwater over a shorter time, leading to increased solute leaching.



**Figure 2: Soil salinity (ECe) at Khirbet As Samra research station**

From the experimental data, especially those collected after just one year of irrigation, it could be hypothesised that soil salinity rises with wastewater irrigation and that rainfall is essential in maintaining suitably low soil salinities in the plant root zone. Yet figure 3 shows data collected from a farm irrigated with reclaimed water for almost 3 decades. These data have been collected from a locality that has had no freshwater input for 28 years, yet the soil salinity has been maintained at a level very suitable for crop production. These data emphasise that with good management, soil solute accumulation can be avoided. For comparison, soil salinity data from an olive plantation irrigated for 18 years is shown. This shows higher soil salinity in the top 50 cm

than in the site irrigated for 28 years, which demonstrates that the soil salinity will rise if leaching is not practised. The deeper rooting depth of the olive trees mean that such high salinity in the soil surface is not detrimental for plant productivity.

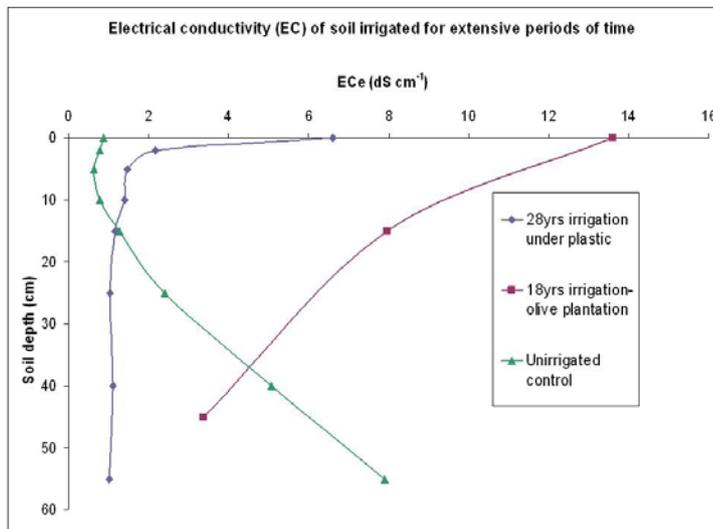


Figure 3 The salinity of soil from farms irrigated with wastewater for extensive periods of time

## Interviews

*Interviews with farmers.* The results of the soil analysis emphasise the importance of management methods in maintaining soil productivity and the farmers interviewed were all asked about the management strategies they employed. It was clear during the interviews that there is a distinct difference in the perception of the water and the use and management of the land between the direct water re-users and the indirect re-users.

A typical comment from a direct re-user was, *“I like the wastewater because before the treatment plant there was no water for supplementary irrigation. I make more money now.”* Directly around the treatment plants the water is being used for the continuous production of fodder crops such as barley, clover and maize. The yield is sold to dairy farms in Jordan and can earn the farmers a substantial income. All farmers around the treatment plants were aware of the beneficial plant nutrients within the water and said how they usually did not add additional chemical fertilisers to the soil which gave them considerable financial savings. It also became clear during the interviews that the farmers felt able to speak with the staff of the wastewater treatment plant if they required any information about the water or if they had any concerns. One example was frequently given of how large amounts of chlorine were previously being added to the wastewater before it was released from the treatment plant. The chlorine was damaging the crops and so the farmers spoke with the plant manager to ask him to reduce the quantity of chlorine. Action was taken to reduce the chlorine additions and irrigation was able to continue successfully without detrimental effects on the crops. No farmers reported any soil salinity issue and most associated the management of this potential risk to the use of flood irrigation around the treatment plants. This results in large quantities of water being applied to the soil regularly giving plenty of leaching of solutes down through the soil profile.

By comparison, the indirect water re-users had a more negative opinion of the water. Typical comments were, *“The water has bad things in it for the plants, there are no good things.”* *“The*

*water quality is bad. There is a high pH and there are many soil born pathogens that come with the water and attack the plants.”* These negative opinions may occur for several reasons. Firstly, the Jordan Valley has historically been irrigated with freshwater from the Yarmouk River. As more and more of this water is redirected to Amman for domestic purposes the freshwater has been replaced by the treated wastewater coming from Khirbet As Samra. Older farmers therefore remember the past when good quality freshwater was available. Secondly, the land of the Jordan Valley is mainly used for the cultivation of high value vegetable and fruit crops. Soil pathogens are both common and very costly to farmers through lost productivity. Any potential for increased risk to the crop, however unscientifically proven, is understandably viewed negatively.

The management methods in the Jordan Valley primarily involve leaching and soil solarisation (a method of sterilising the soil using the sun’s radiation during the summer). Most farmers spoke of the importance of leaching to maintain soil productivity and they said how they aimed to leach annually prior to planting at the start of the season. However, they also said that they rarely have enough water to leach adequately and so are forced to leach either only a small section of their land or to abandon leaching altogether. The low availability of water when it is needed was attributed to both the very limited water resources of Jordan and the weak management of the available resources by the responsible government agency. Farmers were asked if they are able to save money on chemical fertilisers because of those contained within the water. Few farmers recognised any benefits in the form of nutrients coming from the water. Even those who had been trained about the nutrient value of the water admitted to adding chemical fertilisers so as to ensure a good harvest. The cultivation of nutrient demanding vegetable crops in the Jordan Valley and the intensity of cropping also leads most farmers to the decision to add chemical fertilisers, sometimes in excessive quantities.

*Interviews with organisations.* The interviews revealed that 50 per cent of organisations recognised that damage to soil was a risk from water reuse yet none of the organisations considered that water management to reduce this risk was a priority for sustainable development of agriculture using wastewater. The organisations instead spoke frequently of the importance of monitoring to check for adverse effects from irrigation with wastewater. They spoke of a need to train farmers how to manage this water and of the need for more research to provide information to decision makers. All the organisations considered water reuse to be important because of the limited availability of water and its corresponding importance for Jordan's water strategy. Only 7.5 per cent of organisations spoke of the positives from water reuse such as the nutrient benefits.

An issue of considerable importance in Jordan is the allocation of water to different agricultural types and geographical localities and particularly the potential conflict between the direct and indirect water re-users. This was identified by several of the organisations working to develop agriculture in the international and NGO sector:

*“But then there's another challenge coming up. Because the (waste) water quality is better the farmers upstream are more interested in it so it could happen that the water doesn't even reach the Jordan Valley (JV), although the farmers (in the JV) have their water rights. This is a bad thing for the livelihoods of the farmers, and also you have to ask why invest in uphill farming when there's no farming there at the moment. This threatens groundwater resources and damages the good market advantage that the Jordan Valley has during the winter. Because the uphill farming is summer farming. They don't get as much money as the farmers in the Valley as there's a market gap there. It's always an economic decision what or where the water is used. And if they come up with these ideas of growing industrial crops it would be a disaster.”*

*“The water that comes from the Khirbet As Samra means that agriculture can continue in the Middle Jordan Valley. And if this stops the situation will be very bad, I cannot imagine, because there is no (other) water for agriculture. And from a social and economic point of view the (waste) water is the only guarantee for the sustainability of agriculture.”*

It would seem that the topic of water allocation between the indirect and direct agriculture is worthy of serious discussion by planners and decision makers.

## CONCLUSIONS

The interdisciplinary work allows us to draw several conclusions with regards to the sustainability of water reuse. The soil analysis has shown that water reuse for irrigation does alter the soil salinity but it is very important to notice that the salinity changes are highly dependent on several factors such as the quantity of water applied, the rainwater inputs and especially the management methods used on the farm. For this reason it is very important that laboratory results and field experiments are not extrapolated directly to the farm. It is essential that the farmer's knowledge, his perception of the water and the management methods that he chooses to apply are considered when assessing the effects of water reuse on soil. The decisions made by stakeholders away from the farm are also very important in the sustainable management of water reuse and it seems that many organisations do not realise their role in maintaining soil productivity through water management off the farm. It is expected that water reuse for irrigation will increase in the future as greater volumes of urban wastewater are produced, collected and treated. The allocation of this water between direct reuse around treatment plants and indirect reuse at a distance from the plants is worthy of considerable discussion, as there are disadvantages and benefits of each system.

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