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# Water reuse for irrigated agriculture in Jordan: challenges of soil sustainability and the role of management strategies

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## Abstract

Reclaimed water provides an important contribution to the water balance in water scarce Jordan but the quality of this water presents both benefits and challenges. Careful management of reclaimed water is required to maximise the nutrient benefits while minimising the salinity risks. This work utilises a multi-disciplinary research approach to show that soil response to irrigation with reclaimed water is a function of the management strategies adopted on the farm by the water user. The adoption of management methods to maintain soil productivity can be seen to be a result of farmers' awareness to potentially plant toxic ions in the irrigation water (70 per cent of Jordan Valley farmers identified salinisation as a hazard from irrigation with reclaimed water). However, the work also suggests that farmers' management capacity is affected by the institutional management of water. Thirty-five per cent of farmers in the Jordan Valley claimed their ability to manage salinisation was limited by water shortages. Organisational interviews revealed that institutional awareness of soil management challenges was quite high (34 per cent of interviewees described salinisation as a risk from water reuse), but strategies to address this challenge at the institutional level require greater development.

**Keywords:** perceptions; reclaimed water; soil management; salinity; wastewater

## Introduction

Jordan is a country with very limited water resources and 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. Approximately 51 per cent of all domestic wastewater originating from households in urban areas was collected and treated in 2002 and almost all of the treated effluent (reclaimed water) is used for irrigated agriculture (Ministry of Water and Irrigation, 2004). The quantity of wastewater being collected, treated and made available for irrigation is also rising due to increasing urbanisation (Darmame and Potter 2009, 2010; Potter and Darmame, 2010; Potter *et al.*, 2009) resulting in a greater percentage of the country's population being connected to the sewerage network.

The use of reclaimed water for irrigation presents a number of benefits and challenges due to the nature of the water quality. Reclaimed water in arid countries is typically slightly saline and can also have a relatively high concentration of boron (Feign *et al.*, 1991). These ions are potentially plant toxic and crop productivity and the long-term sustainability of the soil can be jeopardised if suitable management of the soil and water is not employed. Despite this challenge, reclaimed water can also contain significant quantities of plant beneficial ions (nutrients) such as nitrogen, phosphorous and potassium. Careful management of the water is therefore required to prevent detrimental effects on soil and crops while benefitting from the "free" nutrients in the water that can enhance yields without the additional costs of chemical fertilisers (Lazarova *et al.*, 2005; Qadir *et al.*, 2010).

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4 Our research into water reuse in Jordan aimed to explore how irrigation with reclaimed  
5 water affects soil sustainability with particular consideration for the role of water  
6 management decisions taken both on and off the farm. Several research aims were  
7 identified:  
8

- 9
- 10 1) How does water reuse affect soil sustainability?
- 11 2) How do farmers using reclaimed water perceive the resource and how do they
- 12 recognise and manage the benefits and limitations?
- 13 3) How do the institutions involved in managing reclaimed water view the resource
- 14 and how do they recognise their role in maintaining soil sustainability?  
15

16 A multidisciplinary research approach involving both the natural and social sciences was  
17 therefore taken in order to explore how aspects of soil sustainability were affected by  
18 irrigation with reclaimed water and how the management of the water on the farm and  
19 away from the farm affected the soil. This approach was selected with the intention of  
20 gaining a wide and holistic view of the numerous processes taking place that result in  
21 soil changes due to irrigation with reclaimed water. It was expected that soil response  
22 would be a function not just of water quality, but also of water management at multiple  
23 scales (from the farmer's field to the government's catchment management plan). As  
24 such, simultaneous investigation of soil and water management at the farm and  
25 institutional level was deemed to be essential in this research.  
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## 28 29 **Research methods**

30  
31 A range of research methods was therefore used which included reclaimed water  
32 sampling and standard chemical analysis (including pH measurement, electrical  
33 conductivity measurement and concentrations of major cations and anions determined  
34 with inductively coupled plasma optical emission spectroscopy and ion chromatography  
35 respectively). Soils which had been irrigated with reclaimed water for known periods of  
36 time were sampled and analysed to determine the chemical character of the soil  
37 saturation extract, which is commonly used to represent the soil solution (Bressler *et al.*,  
38 1982). The standard method given by Rowell (1995) was followed. Water and soils  
39 were sampled from the irrigated area surrounding Khirbet As Samra wastewater  
40 treatment plant (located in the arid eastern desert of Jordan), Ramtha wastewater  
41 treatment plant (located in the semi-arid northern highlands of Jordan) and Deir Alla  
42 (located in the central Jordan Valley, where a mixture of freshwater and reclaimed water  
43 from the King Talal Reservoir is used for irrigation) (see Carr, 2009 for further details).  
44  
45

46 Following well-established methodological approaches (Kitchen and Tate, 2000; Desai  
47 and Potter, 2006), semi-structured interviews were conducted with a total of 39 farmers  
48 irrigating with reclaimed water to document and investigate their experiences and  
49 perceptions and the strategies they employ in seeking to manage soil risks from  
50 reclaimed water on the farm. These were mainly conducted with the assistance of a  
51 translator with advanced knowledge of agricultural systems in Jordan. The role of  
52 international agencies, governmental, non-governmental, private and research  
53 organisations in water reuse was also considered through semi-structured interviews  
54 with a total of 29 organisational representatives. These interviews paid particular  
55 attention to the effects of water resource decision-making on water quality and water  
56 quantity provision to the farm, and the effect of these actions for the soil management  
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3 strategies adopted by the farmer. Interviews were either recorded or notes were taken  
4 and these were typed up or transcripts prepared immediately after the interviews.  
5 Following the guidelines of Kitchin and Tate (2000), each “data bit” (piece of information)  
6 within the transcripts was then coded following a coding framework developed for each  
7 of the interview groups (farmers and organisations). Through examining each similarly  
8 coded group of data bits, similarities and differences became clear and narratives could  
9 be developed around specific themes.  
10

## 11 12 13 **Results and Discussion**

14  
15 Water sampling and analysis, combined with data available in the literature, revealed  
16 that the reclaimed water from the selected study sites in Jordan contained significant  
17 quantities of both plant beneficial ions and potentially plant toxic ions (Table 1). The  
18 phosphate in the reclaimed water is of particular benefit as it has the potential to meet a  
19 substantial proportion of crop requirements at Khirbet As Samra and in the Jordan  
20 Valley, depending on the crops grown and the intensity of cropping. At Ramtha, the  
21 concentration of phosphate is lower due to the removal of this nutrient during wastewater  
22 treatment. The removal of phosphate during treatment is perhaps questionable due to  
23 the use of the water for irrigation directly around the wastewater treatment plant and the  
24 value of the phosphate for crop productivity (Carr, 2010).  
25  
26

27 The chloride, sodium and boron in the irrigation water have the potential to reach  
28 concentrations in the soil beyond which a reduction in crop productivity can be  
29 experienced, based on guidance by the Food and Agriculture Organisation (Ayers and  
30 Westcott, 1985). The effect of solute accumulation is highly dependent on the sensitivity  
31 of the crop to these ions (Maas, 1987). Additionally, a high proportion of sodium relative  
32 to other positively charged ions in the soil can cause soil structural problems (Oster and  
33 Jayawardane, 1998). The sodium adsorption ratio (SAR) is an indicator of the sodium  
34 risk and the data suggest that the water at Khirbet As Samra may present a soil sodicity  
35 risk, but this would be dependent on the physical properties of the soil and its response  
36 to elevated sodium (Rowell, 1994).  
37  
38

39 **Table 1** Selected water quality parameters for reclaimed water from Khirbet As Samra, Ramtha and the King  
40 Talal Reservoir based on samples collected in the field and available published data (GTZ, 2005; Al-Zu'bi,  
41 2007; Ammary, 2007; Bashabsheh, 2007)

42 (near here)  
43  
44

45  
46 Analysis of soils irrigated with reclaimed water for extended periods of time showed that  
47 the management methods employed by the farmers altered the accumulation of  
48 potentially plant toxic ions in the soil. Figure 1 shows how soil in the Jordan Valley  
49 which has been irrigated with reclaimed water for 28 years has a low solute  
50 concentration (electrical conductivity in the soil saturation extract) in the crop root zone.  
51 This reflects the regular application of leaching water by the farmer in order to transfer  
52 solutes through the soil profile. In comparison, the electrical conductivity of the soil  
53 irrigated for 18 years at Khirbet As Samra, shown in Figure 1, is much higher throughout  
54 the soil profile and reflects how leaching has not taken place on this soil. Leaching has  
55 not been conducted because the land has been used for olive cultivation, olives having a  
56 deeper rooting depth and so not being sensitive to salinity in the upper soil profile.  
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3 **Figure 1.** Soil salinity (measured by the electrical conductivity of the soil saturation extract) in soils irrigated  
4 with reclaimed water for extensive periods of time (error bars show standard error from the mean)  
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6 (near here)  
7

8 Interviews with farmers showed a high awareness to salinity risk in the Jordan Valley  
9 and 70 per cent of farmers identified soil salinisation as a hazard due to irrigation with  
10 reclaimed water. In contrast, farmers using reclaimed water directly around the  
11 wastewater treatment plants of Ramtha and Khirbet As Samra were not so concerned  
12 about salinity (18 per cent). This is likely to be due to the use of flood irrigation directly  
13 around the treatment plants which results in the regular flushing of the solutes through  
14 the soil. Flood irrigation is possible around the treatment plants due to high water  
15 availability and the use of irrigation as a form of waste disposal. Drip irrigation is used in  
16 the Jordan Valley as a result of low availability of water, resulting from the high intensity  
17 of cropping, both seasonally and spatially (Molle *et al*, 2008).  
18

19  
20 The interviews with farmers in the Jordan Valley revealed that although awareness of  
21 salinity risk was high, and the need for leaching was recognised, 35 per cent of the  
22 farmers interviewed described how their capacity to leach was limited due to water  
23 shortage. Farmers acknowledged that this was a result of the environmental conditions  
24 of low rainfall and high evaporation in Jordan, but it was also noted by several farmers  
25 that institutional weaknesses affected their ability to maintain the soil in a sustainable  
26 manner. Issues identified included: the distribution of water between farmers, with some  
27 farmers describing how they received very little water while their neighbour received  
28 plenty; the seasonal distribution of water, with resources being supplied in higher  
29 quantities than required in winter and not supplied in sufficient quantities at other times  
30 of the year; inadequate management of water infrastructure, such as canals; and the  
31 enforcement of regulations to protect the quality of the irrigation water (for example,  
32 though preventing industrial waste entering the domestic wastewater system).  
33

34  
35 Interviews with organisations showed that there was high awareness among this  
36 stakeholder group with regard to the protection of the soil resource (34 per cent of  
37 interviewees identified salinisation as a risk from water reuse). However, no  
38 organisations discussed their role in protecting soil sustainability through ensuring the  
39 water provided to farmers is of a suitable quality and quantity to meet their needs.  
40 Awareness of risks from reclaimed water quality was present, but this was primarily with  
41 regards to human health protection.  
42

## 43 44 **Conclusions**

45  
46 This work has shown that the use of reclaimed water for irrigation in Jordan does have  
47 the capacity to affect the soil in a detrimental manner, but the effect of the water on soils  
48 can be managed through the application of suitable strategies on the farm. Farmers  
49 recognise the challenges and the benefits of using reclaimed water for irrigation, and  
50 endeavour to manage the risks to minimise the detrimental effects on the soil and to  
51 maintain productivity. However, their capacity to manage their soil is intricately  
52 connected to the management of water at the institutional level through the control of  
53 water quality and the provision of water in quantities and at the times it is required by  
54 farmers. It is stressed that the multidisciplinary approach adopted has proved to be of  
55 immense value for this study due to its capacity to both document physical processes  
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3 taking place in the soil, and to link these directly with processes of water management  
4 taking place at the farm- and institutional-levels.  
5  
6

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10 thank all the farmers and organisation representatives who generously gave their time  
11 for the interviews and the superb and dedicated translation assistance of a number of  
12 invaluable individuals.  
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### 15 **References**

- 16  
17  
18 Al-Zu'bi, Y. (2007) Effect of irrigation water on agricultural soil in Jordan Valley: An  
19 example from arid area conditions. *Journal of Arid Environments*. **70** pp. 63-79  
20  
21 Ammary, B.Y. (2007) Wastewater reuse in Jordan: Present status and future plans.  
22 *Desalination* **211** pp. 164-176  
23  
24 Ayers, R.S. and Westcott, D.W. (1985) Water Quality for Agriculture. *Irrigation and*  
25 *Drainage Paper* **29**. Rev 1. Food and Agriculture Organisation of the United Nations,  
26 Rome, Italy  
27  
28 Bashabsheh, I.M. (2007) *Impact of treated wastewater on soil properties and cut flower*  
29 *production under drip irrigation systems*. Unpublished MSc Thesis. Jordan University of  
30 Science and Technology, Jordan  
31  
32 Bressler, E., McNeal, B.L. and Carter, D.L. (1982) Saline and Sodic Soils: Principles-  
33 Dynamics-Modeling. *Advanced Series in Agricultural Sciences* **10**. Springer-Verlag,  
34 Berlin, Germany  
35  
36 Carr, G. (2010) Water reuse for irrigated agriculture in Jordan: soil sustainability,  
37 perceptions and management. Chapter 24 In: Mithen, S. and Black, E. (eds) *Water, Life*  
38 *and Civilisation*. Cambridge University Press/UNESCO International Hydrology Series,  
39 UK  
40  
41 Carr, G. (2009) *Water reuse for irrigated agriculture in Jordan: soil sustainability,*  
42 *perceptions and management*. Unpublished PhD Thesis. Department of Soil Science  
43 and Department of Geography, University of Reading, UK  
44  
45 Darmame, K. and Potter, R.B. (2009) 'Gestion de la rarete de l'eau a Amman:  
46 rationnement de l'offre et pratiques des usagers', *Espaces et Societies*, 139, in press  
47  
48 Darmame, K. and Potter, R.B. (2010) Political discourses and public narratives on water  
49 supply issues in Amman, Jordan. Chapter 28 in: Mithen, S. and Black, E. (eds) *Water,*  
50 *Life and Civilisation*. Cambridge University Press/UNESCO International Hydrology  
51 Series, UK  
52  
53  
54 Desai, V and Potter R B (2006) *Doing Development Research*, Sage: London, Thousand  
55 Oaks and New Delhi  
56  
57  
58  
59  
60



1  
2  
3 Feign, A., Ravina, I. and Shalhevet, J. (1991) *Irrigation with Treated Sewage Effluent*.  
4 Springer-Verlag, Israel  
5

6 GTZ (2005) *Long-term groundwater and soil monitoring concept – Final Report 2005*.  
7 Reclaimed Water Project of the Deutsche Gesellschaft für Technische Zusammenarbeit,  
8 Amman, Jordan  
9

10 Kitchin, R. and Tate, N.J. (2000) *Conducting Research in Human Geography: Theory,*  
11 *Methodology and Practice*. Prentice Hall, UK

12 Lazarova, V., Bouwer, H. and Bahri, A. (2005) Water Quality Considerations. pp. 31-63  
13 In: Lazarova, V. and Bahri, A (eds) *Water reuse for irrigation: agriculture, landscapes*  
14 *and turf grass*. CRC Press, Boca Raton, USA  
15

16 Maas, E.V. (1987) Salt tolerance of plants. In: Christie, B.R. (ed.) *The Handbook of*  
17 *Plant Science in Agriculture*. CRC Press, Boca Raton, Florida, USA  
18

19 Ministry of Water and Irrigation, Jordan. (2004) *National Water Master Plan of Jordan*,  
20 Amman, Jordan

21 Molle, F., Vernot, J.P. and Hassan, Y. (2008) Irrigation in the Jordan Valley: Are water  
22 pricing policies overly optimistic? *Agricultural Water Management* **95** pp. 427-438  
23

24 Oster, J.D. and Jayawardane, N.S. (1998) Agricultural management of sodic soils.  
25 Chapter 8 in Sumner, M.E. and Naidu, R. (eds) *Sodic Soils: Distribution, Properties,*  
26 *Management, and Environmental Consequences*. Oxford University Press. New York,  
27 USA  
28

29 Potter, R.B., Darmame, K., Barham, N. and Nortcliff, S. (2008) “Ever-growing Amman”,  
30 Jordan: urban expansion, social polarisation and contemporary urban planning issues.  
31 *Habitat International* **33**(1) pp. 81-92  
32

33 Potter, R.B. and Darmame, K (2010) ‘Contemporary social variations in household water  
34 use, management strategies and awareness under conditions of water stress: the case  
35 of Greater Amman, Jordan’, *Habitat International*, 15, 115-124  
36

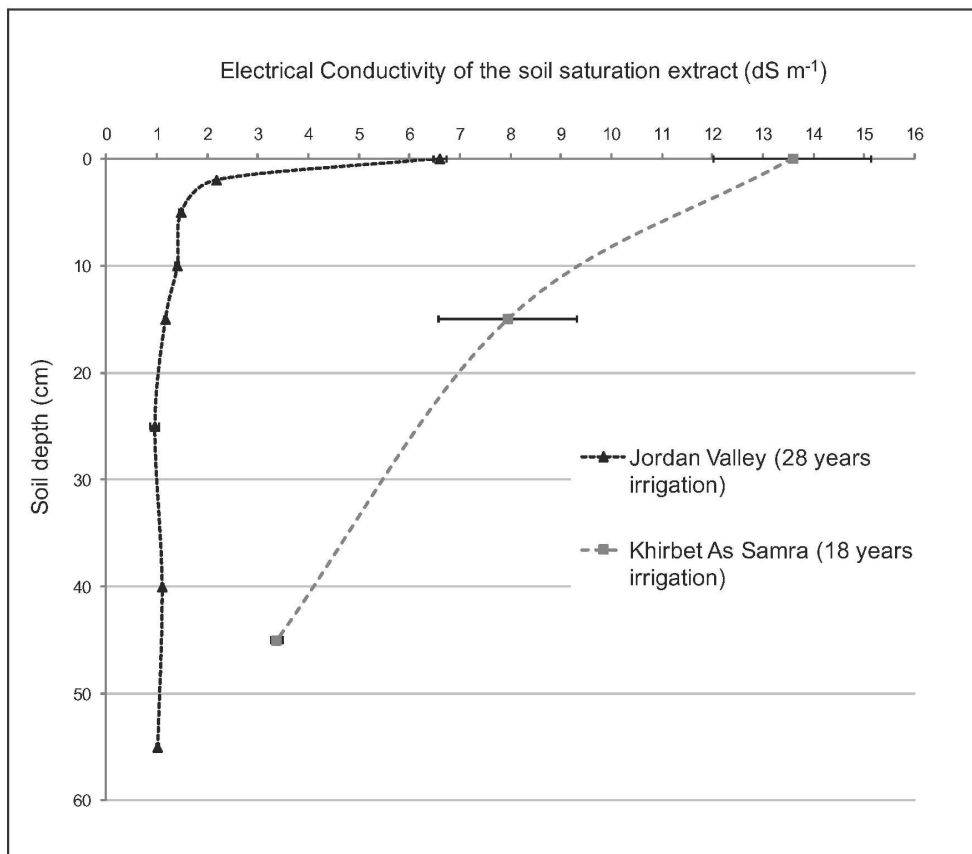
37 Qadir, M., Wichelns, D., Rashid-Sally, L., McCornick, P.G., Drechsel, P., Bahri, A. and  
38 Minhas, P.S. (2010) The challenges of wastewater irrigation in developing countries.  
39 *Agricultural Water Management* **97** (4) pp. 561-568  
40

41 Rowell, D.L. (1994) *Soil Science. Methods and Applications*. Pearson Education. UK  
42  
43  
44  
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Location	Potentially plant beneficial ions in the irrigation water (mg L <sup>-1</sup> )					Potentially plant toxic ions in the irrigation water (mg L <sup>-1</sup> )			Additional parameters		
	Sulphate (SO <sub>4</sub> )	Calcium (Ca)	Potassium (K)	Magnesium (Mg)	Phosphate (PO <sub>4</sub> )	Chloride (Cl)	Sodium (Na)	Boron (B)	Electrical Conductivity (dS m <sup>-1</sup> )	pH	Sodium adsorption ratio (SAR)
Khirbet As Samra	65.09	44.55	31.32	27.22	35.63	364.61	261.14	0.91	2.14	7.86	7.67
Ramtha	104.66	49.71	32.97	34.19	6.80	398.76	232.46	0.73	1.71	8.21	6.30
King Talal Reservoir	90.78	50.09	15.74	31.39	21.74	276.66	125.67	0.54	1.91	7.85	1.92
Tap water (Amman)	52.90	56.47	5.36	20.61	4.13	153.38	65.41	<0.0016	0.79	6.90	1.89

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