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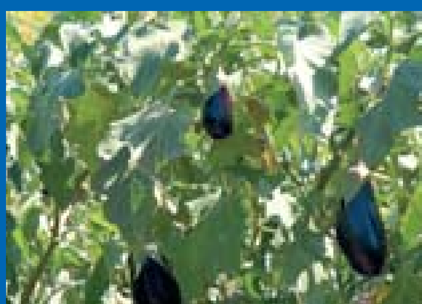
Sustainable Management of Wastewater for Agriculture

Proceedings of the First Bridging Workshop

11-15 November 2007
Aleppo, Syria

Bridging Workshops

Editor: Manzoor Qadir



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Citation:
Qadir, Manzoor (ed). 2008. Sustainable Management of Wastewater for Agriculture: Proceedings of the First Bridging Workshop, 11-15 Nov 2007, Aleppo, Syria. International Center for Agricultural Research in the Dry Areas, (ICARDA), PO Box 5466, Aleppo, Syria; and International Water Management Institute (IWMI), Colombo, Sri Lanka. vi + 133 pp

ISBN 92-9127-213-4

Acknowledgments

ICARDA and IWMI gratefully acknowledge the financial support and technical input received from the International Development Research Centre (IDRC) and Wageningen University.

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Foreword

The context

As much as 60% of the global population is expected to suffer water scarcity by the year 2025. With increasing competition for good-quality water among different sectors, availability of water for agriculture will likely decline, especially in water-scarce countries. The water taken away from agriculture is diverted to household, municipal, and industrial activities. Since the use of freshwater for these activities generates wastewater, the volume of wastewater has increased. The productive use of wastewater has also increased, with millions of small-scale farmers in urban and peri-urban areas of developing countries using wastewater sources to irrigate a range of crops. Water-scarce countries will have to increasingly rely on such alternative water resources to narrow the gap between freshwater demand and supply.

There is limited available information on the extent of wastewater resources that could be potentially exploited in water-scarce countries. Even where data are available, assessment of these resources is complicated by the different criteria used to identify and categorize them. In addition, information on the productivity potential of wastewater, its impacts on the environment, and on the social and economic conditions of the dependent farming communities, is also limited.

Recycling of treated wastewater needs to be promoted. In many parts of the developing world, large amounts of untreated or inadequately treated wastewater are currently used by farmers, usually in an uncontrolled manner – raising concerns about public health and the environment. This situation warrants rethinking of the ways in which wastewater is handled and reused in crop production systems. The development of appropriate technical and policy options for wastewater in water-scarce countries offers great promise for the foreseeable future. However, the capacity, skilled human resources, and research-based knowledge are lacking in developing countries to tackle the complex issues arising from the agricultural use of wastewater.

‘Bridging’ Workshops

ICARDA and IWMI are working with national and regional institutions to develop management practices that can significantly increase agricultural productivity and income of communities that rely on wastewater irrigation. To bridge the knowledge gap between advanced research institutions and young developing-country researchers, ICARDA and IWMI have launched the 'Bridging Workshops' addressing different aspects of water resources management. These workshops are expected to guide young researchers towards the state-of-the-art of multidisciplinary, cutting edge research, applying an open-space and open-mind environment where participants are mentored by experienced scientists, and encouraged to interact and ask questions they could never ask in conventional workshops. This initiative will involve lead international scientists and young and mid-career scientists from developing-country agricultural research institutions in the exchange of information and experience.

This publication summarizes the proceedings of the first 'Bridging Workshop' held during 11-14 November 2007 at ICARDA headquarters in Aleppo, Syria. The workshop had three types of sessions. The stimulating sessions led by lead scientists/resource persons focused on predefined topics. The country sessions consisted of presentations of case studies from developing-country participants. The final session summarized research challenges and gaps as identified in the previous sessions and workshop discussions.

Based on extensive discussions, the participants prioritized important research and development related issues addressing wastewater use in agriculture. The two most important topics were bridging the gap between research and farmer practice in low-income countries; and developing holistic approaches for sustainable management of wastewater in agriculture. These two topics were followed by another priority set of three topics, including: Upstream-downstream challenges for wastewater management; impacts of wastewater on livelihoods and health; and stakeholder involvement throughout the planning and operational processes of wastewater management.

The financial support of the International Development Research Centre, Canada, and Wageningen University, The Netherlands, for organizing the workshop and publication of the proceedings is gratefully acknowledged.
Based on the promising outcome of this first workshop, further bridging workshops on challenging aspects of water resources management are expected to be held.

Pay Drechsel
Theme Leader
Water Quality, Health & Environment
IWMI

Theib Oweis
Director
Integrated Water & Land Mgmnt. Program
ICARDA

Stimulating Sessions

Stimulating Sessions

Session 1 The reversed water chain approach: optimizing agricultural use of urban wastewater

Resource Person Frans Huibers, Centre for Water and Climate, Wageningen University, The Netherlands

Key message: Addressing water resources management at different scales, from the perspective of downstream uses vis-à-vis requisite water quality, helps in setting the criteria for designing urban water flows, wastewater treatment, and upstream management of water resources.

The objective of the session was to introduce the conceptual approach of the 'water chain'. This explains how urban water flows, from its upstream source towards downstream use in agriculture, before being discharged into natural ecosystems. It is suggested that handling of this water at different stages should be done from the perspective of downstream uses. In a reversed approach, the ultimate user of the treated wastewater sets the criteria for designing urban water flows, including wastewater treatment plant characteristics and treatment levels, and upstream handling of the water.

The session was initiated with a presentation elaborating on the 'water chain approach'. Following the presentation, five groups of participants were formed. They were asked to develop research questions that are linked to this water chain approach. In general, the groups came up with ideas and suggestions for the downstream part of the water chain, linked to the use of poor-quality water in downstream irrigation and often questioning the fate of nutrients and heavy metals. Specific questions and comments raised after discussion in different groups included:

Nutrient levels in groundwater. What is the major source of possible groundwater pollution – the use of wastewater or the sometimes excessive application of chemical fertilizers by farmers?

From the discussions it became clear that there is limited insight into the plant-available nutrient content in effluent and even less knowledge on fertilizer use by farmers. It is a fact that most farmers using wastewater do not take the nutrient content of the water into consideration, leading to excessive additional applications through manure and/or chemical fertilizers. This is probably due to, on the one hand, lack of monitoring and communication on actual water composition, and on the other hand, lack of insight on the part of farmers to translate such information into their fertilizer management plans. Nutrient budgeting could be used as a first step to develop better insight in addressing field realities. A further problem is that wastewater, even when treated, can contain varying levels of nutrients which makes management at the farmer level difficult. Such problems should be overcome if wastewater is to be used effectively.

Long-term effects on soil. What are the long-term effects of applying organic matter and heavy metals (through wastewater irrigation and/or sludge application) on soils and soil biology and micro-organisms?

Certainly, there are many unknowns about the long-term effects on soil characteristics from using wastewater and sludge. Both positive and negative long-term effects on soil biology and microorganisms are reported; the actual processes depend on the composition of the water, soil characteristics, and land use systems. Heavy metals may accumulate, but upstream measures including the separation of industrial flows from domestic flows (probably the most effective and least expensive action) would avoid further build-up and subsequent negative effects.

Water quality standards. What are the water quality standards typically required for specific uses of the treated wastewater?

Through tertiary treatment, any type of effluent with desirable characteristics could be achieved, but only at high costs, which are not affordable for developing countries using their own resources. To save on this level of wastewater treatment, equilibrium should be sought between effluent quality and quality requirements for specific downstream agricultural uses, such as irrigating vegetables, cultivating grain crops, forages and fruit trees, and agroforestry. With consideration for the ultimate use of wastewater, management structures should be set up to link farmers and consumers.

Wastewater treatment design. In the different groups, several points were raised that have a relationship with options for wastewater treatment design. It was felt that more research should be done to investigate the value of constructed wetlands as a treatment technique. On the upstream side, designers should develop better insight into point-source pollution and should consider decentralized approaches to wastewater collection and treatment.

Session 2 — Low-cost decentralized wastewater treatment and the way forward

Resource Persons

Manzoor Qadir, ICARDA, Aleppo, Syria; and IWMI, Colombo, Sri Lanka

Liqa Raschid-Sally, IWMI, West Africa, Accra, Ghana

Rafig Azzam, Institute of Engineering Geology and Hydrogeology, Aachen University, Germany

Key message: With fewer technological and economical inputs than conventional centralized wastewater treatment systems, decentralized wastewater treatment offers a sustainable answer to environmental concerns about water pollution and land degradation, particularly in areas where an increasing population uses increasing volumes of water, and the water network is often inadequate and unreliable.

The objectives of the session were to address different elements of decentralized wastewater treatment, to compare centralized and decentralized wastewater treatment approaches, and to focus on a decentralized approach as a potential option for those areas where centralized systems do not work efficiently for several reasons. The presentation addressed different types of decentralized wastewater treatment systems and their salient features, steps involved in the treatment process, comparison of mechanical and biological systems, and anticipated advantages of decentralized systems.

Owing to increasing urbanization and high population pressure in suburban areas and slum districts, population grows faster than the provision of water supplies and wastewater disposal and treatment infrastructure, which in most cases is based on a centralized system. In cities where population increases rapidly, the sanitation infrastructure cannot cope with the increased levels of water consumption and wastewater discharge. In many cases, sanitation systems are in a bad condition (encrusted, covered in weed growth, and blocked by stones). With no adequate wastewater management system, conditions worsen, mainly because the system discharges partially treated wastewater. In this context, decentralized wastewater treatment represents a substitute solution, particularly in developing countries, where it allows flexibility in the design of both the water supply system and the wastewater disposal system. Decentralized systems, in which wastes are transported over a shorter distance, can be designed to use less water. The reuse of treated wastewater at a local level can also be built into the system. Both these approaches contribute to water demand management, propose a sustainable answer to environmental concerns surrounding water pollution and land degradation, and can be provided with less technological and economical effort than conventional centralized wastewater treatment systems. Figure 1 shows a simplified schematic representation of decentralized wastewater treatment. The following advantages of decentralized wastewater systems are envisaged:

- An extensive sewer system is not necessary
- Low-cost solutions are possible
- They are applicable in densely as well as sparsely populated areas
- Segregation of industrial wastewater from other forms of wastewater is possible
- Environmentally feasible wastewater treatment and sustainable water management are possible.

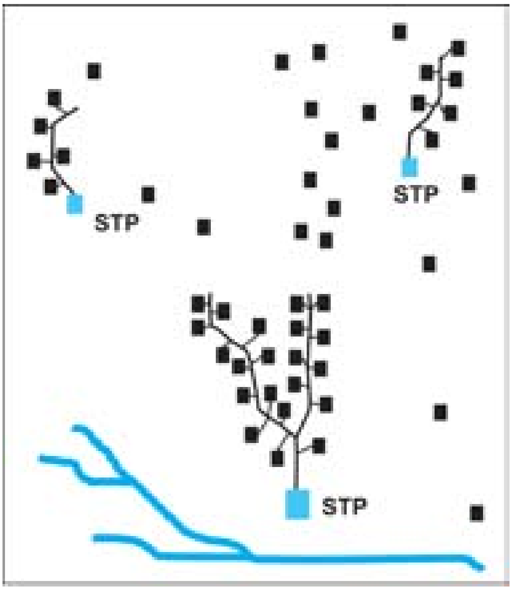

Fig. 1 A simplified schematic presentation of decentralized wastewater treatment. STP = sewage treatment plant.

Session 3 Moving towards a more holistic approach to research on wastewater and graywater use: where are we at?

Resource Person Mark Redwood, International Development Research Centre (IDRC), Canada

Key message: Merging biophysical elements of wastewater management with non-biophysical dimensions – social, economic, cultural, and policy - and involving all stakeholders can address the complex challenge of environmentally feasible use of wastewater in developing countries.

The session started with a presentation on the non-biophysical dimension of wastewater use, and addressed the question, how do we conduct research so that biophysical elements merge well with social, economic and cultural questions? The specific goals of this session were:

- Using examples from Senegal, Jordan and Palestine, to illustrate the importance of complementing physical science research with socio-economic research that seeks to understand motivations for behavior
- To outline the complexity of the challenge of creating responsive policy. This challenge is not only biophysical, but also needs the involvement of actors from many different disciplines, as well as research that takes into account social, cultural and economic factors
- To highlight issues and questions relating to the behaviors of those who use wastewater, both treated and untreated, in order to better inform research questions posed in the future

An overview presented salient issues relating to current work on wastewater. These included the economic benefits of wastewater use, farmer attitudes to wastewater use, and experience from the Middle East and North Africa (MENA) with examples from Jordan and Palestine, and from sub-Saharan Africa (SSA) with an example from Senegal. It also touched on a couple of approaches that could provide some guidance to researchers in their efforts to deliver more holistic research (the Livelihoods Approach, the 'Eco-health' Approach, and Outcome Mapping).

The peri-urban interface (PUI) was brought into the discussion. On the one hand, the PUI contains land and agricultural systems that are dedicated to feeding the urban market, but on the other hand, high settlement density and unclear administrative responsibilities make the PUI a real policy challenge. Examples were pulled from work on wastewater use in Senegal (Dakar) and graywater use in Jordan (Karak), to present data and to illustrate some of the points raised.

The second part of the session was interactive with three small groups each representing the 'voice' of a different stakeholder: a farmer, a municipal health commissioner, and a Ministry of Health official. Each group was asked to read a sheet about the particular 'challenge' of that stakeholder. The stakeholder sheet had leading questions for individual group discussion, which lasted about 30 minutes. Following this, there were small presentations from each group. The goal of the exercise was to draw out creative responses from each group with regard to factors that need consideration when developing policy-level interventions. The perspectives of the three groups prompted questions relating to policy development in wastewater use.

Farmer. The group representing a farmer came up with a range of perspectives on on-farm wastewater use, health care, financial support, irrigation-level interventions, marketing, and wastewater treatment. The list of proposals included:

- Using wastewater on dedicated areas, thereby concentrating wastewater and making it easier to monitor wastewater use
- Establishing micro-credit systems to facilitate use of advanced irrigation methods that include risk reduction, i.e. minimizing direct contact with the wastewater
- Providing vaccination and chemotherapy for farmers
- Differential pricing for products associated/not associated with wastewater
- Providing incentives that include increased prices for products grown with freshwater irrigation, which would entail the need for subsidies and enforcement. This prompted a debate about the feasibility of differential pricing and labeling
- Participatory involvement of farmers when it comes to the development of wastewater treatment options

Municipal authorities. The team looking at the municipal level perspective on policy development noted that, since municipalities generally control markets, market level interventions are appropriate. Proposals included:

- Providing education and programs on basic hygiene, contact avoidance, and washing – to be disseminated at the market where consumers and producers are in contact
- Restricting the consumption of raw vegetables that may have been contaminated
- Providing alternatives to communities before enforcing a ban on using untreated, partly treated or diluted wastewater

- Developing an action plan and running an awareness campaign such as the Multi-stakeholder Policy Formulation and Action Planning (MPAP) of the Resource Centre for Urban Agriculture and Food Security (RUAF)
- Assuring communities that municipal policies are based on incentives as opposed to punishments

National level authorities. A major impediment to better policy on wastewater use is the lack of coordination between different ministries such as health, environment and agriculture. Moreover, the connection and communication between ministries responsible for urban development and health and municipal authorities are not always strong. The group presented the following options:

- Formulating a committee of multiple ministries examining different dimensions of wastewater – production, treatment, awareness, agricultural use, product marketing
- Preparing standards revealing the levels of contamination in wastewater-irrigated soils and crops - a monitoring and warning system
- Maintaining quality management systems addressing crop quality for local use and export markets
- Implementing WHO guidelines as the basis for policy development on wastewater use.

Session 4 What can be done when wastewater treatment does not work?

Resource Persons

Thor Axel Stenström, Swedish Institute for Infectious Disease Control, Solna, Sweden

Pay Drechsel and Liqa Raschid-Sally, IWMI, West Africa, Accra, Ghana

Key message: A greater understanding of urbanization and sanitation and their links with health safety and potential risks, and the application of non-technical handling practices for wastewater-based agriculture can minimize risks to a greater extent than a costly technical treatment, particularly in resource-poor situations.

Considering different aspects of wastewater generation and defecation, the session addressed three major aspects: (i) urbanization and sanitation and their links with health safety and potential risks; (ii) wastewater irrigation in urban and peri-urban areas and related benefits and risks; (iii) non-technical handling practices for wastewater-based agriculture.

Urbanization and sanitation links with health safety and potential risks. The session first addressed 'urbanization and sanitation vis-à-vis safety and risks' with a cautious note that in the year 2008, the world will reach an invisible but momentous milestone: for the first time in history, more than half its human population will be living in urban areas which means both that pressure on sanitation systems (or the lack thereof) will be immense and that pressure on the transportation of food and water into cities will rapidly increase.

While using sewer sanitation, we usually 'flush and forget', but what is happening down the drain? Open defecation and wastewater generation may have implications for downstream communities where water use and water related activities are prevalent, with the potential for diseases from the upstream outlets. Several unsanitary practices are common around the world. These relate to open defecation, wastewater discharge, and/or indiscriminate dumping of, for example, faecal sludge. However, sometimes we are fooled by our senses into underestimating the implications of unsanitary practices. Is the surface water clean at resorts, swimming or recreational sites, or when water is coming out from the taps? Even if it appears clean and tastes good, it is the 'up-use' history of the water, which determines associated risks and their intensity. This also relates to crops and their intended use, at the farm as well as at market. Based on the World Health Organization (WHO) guidelines revised in 2006, several risk reduction approaches can be taken when irrigating with wastewater to ensure safety for consumers. These include:

- Wastewater treatment
- Crop restriction
- Wastewater application techniques that minimize contamination, e.g. drip irrigation
- Withholding periods to allow pathogens to die off after the last wastewater application
- Hygienic practices at food markets and during food preparation
- Health and hygiene promotion
- Washing, disinfection and cooking of produce
- Chemotherapy and immunization

A suitable combination of these approaches can achieve the target of reducing risk by 6-7 logs as suggested by the WHO for unrestricted (or lower for restricted) irrigation. An appropriate combination of these approaches stems from the different types of wastewater treatment available, the time taken for organisms to die off in the field – on the crops or in the soil, and the method of wastewater application as well as post-harvest practices. The application of these factors is important within a risk management framework, especially in light of the foreseeable concentration of people to and within urban areas. The current situation with faecal sludge dumping, indiscriminate disposal of wastewater both in surface water bodies and in marine areas strongly points to the inappropriate or absent management of urban waste and wastewater. In some regions, such as sub-Saharan Africa, sewer networks are collecting often only a small percentage of the generated wastewater. In addition, the few existing wastewater treatment plants are usually non-functional or overloaded with wastewater subject to treatment.

Wastewater irrigation in urban and peri-urban areas and related benefits and risks. If we are targeting a 3-log reduction through wastewater treatment and reservoir storage, a further 3-4 log reduction is needed. In addition, if we anticipate large variations in additional faecal input, we may need to account for further additional reduction at the agricultural sites. The question is how this can be achieved at the farm level. In the case of the Jordan Valley, farm pools with further storage give a 'time-dependent reduction' in the microbial load. If a retention time of weeks is maintained, it functions as an additional reduction barrier to the microbial load. If the withholding time (at least 2-4 weeks) is applied between the cessation of irrigation and the harvest period, risks are substantially reduced. From a risk management perspective, such withholding time should be advocated. Irrigation methods such as drip, and the choice of crops – trees (olive, citrus, almond) or vegetables (tomato, cucumber, different types of salad crops) – define the level of risk reduction. Washing of wastewater-irrigated vegetables and fruits in good-quality water should be promoted as an additional safeguard. However, washing of vegetables or fruits should never be done in canal water or storage pond water. In addition, post-harvest practices and market level interventions are essential in defining the final risk level.

Selecting appropriate crops while using wastewater for irrigation is an essential factor in minimizing risk under specific conditions; for example, energy crops pose a very low risk if workers' exposure is accounted for and where subsequent implications for surface water and groundwater can be minimized. Thus the site selection criteria become highly important in this respect. Furthermore, assurances of high security and export grants based on specialized agriculture such as exotic vegetables and ornamental plants, can stimulate risk management. However, in the latter situation, the risk management plan must clearly include a source protection or treatment component.

The current situation is different, however; farmers use polluted irrigation water for the production of high-value crops in and around about 75% of cities in the developing world. The situation is critical and requires pragmatic solutions as the wastewater-irrigated sector supplies up to 90% of most perishable vegetables consumed in these cities. Further, it supports many jobs and livelihoods. For example, women in sub-Saharan African cities dominate vegetable marketing (more than 95%). And, the average income of urban farmers is above that of rural farmers. Similarly, women (traders) can earn more than men (farmers), allowing urban farmers and women traders to cross the poverty line.

However, this urban food supply chain can result in risks to large numbers of consumers. In Accra, for example, more than 200,000 people consume urban-produced vegetables every day. It is, however, clear that a well-managed system of food growing can substantially enhance crop productivity and quality.

Risks can be rated in relation to type of crops and how they are grown. For example, the risks are much less for those crops that grow slowly, are not eaten (garden plants and energy crops), or that are generally cooked before human consumption. In addition, risks can be minimized if a withholding time is institutionalized. Concerns are therefore primarily directed towards root and leafy crops that are eaten raw. For example, epidemiological studies in Mexico reveal a relationship between green tomatoes (used in salsa) and onions, and a higher incidence of diarrhea.

Non-technical handling practices. WHO guidelines apply a holistic management approach, which includes multiple barriers at different points – wastewater generation, farmers using wastewater, traders using wastewater-irrigated crops such as street food, kitchens, and consumers.

In Ghana, several wastewater irrigation and management practices have led to risk reductions. These include: the cessation of irrigation well before harvest; improving wastewater application methods to reduce splashing – less splashing create less recontamination of the crop surface from the soil; simple wastewater filtration, which reduces the number of helminth eggs; drip irrigation, which limits contamination of leaf surfaces; well-maintained furrow irrigation, which reduces contamination levels; and simple precautions such as not stirring sediments into ponds. But wastewater is not the only source of contamination for produce. To accurately assess the impact from wastewater, different contamination pathways must also be considered, for example, the use of animal manure. Post-harvest practices, such as washing vegetables with clean water, and different market practices and storage of food products are also important. This includes good practices in home kitchens or in urban fast food premises.

Session 5 — Linking sanitation and agricultural sectors for more effective resource recovery through multi-stakeholder platforms and learning alliances

Resource Person Liqa Raschid-Sally, IWMI West Africa, Accra, Ghana

Key message: Continuous dialogue and learning through multi-stakeholder platforms that link sanitation and agriculture sectors help in effective resource recovery, improved sanitation, contaminant reduction, and the promotion of hygiene behavior as well as wastewater treatment, disposal, and use in agriculture.

The main objective of the session was to show how resource recovery can be made more effective, through dialogue and learning in multi-stakeholder platforms (MSPs) that link the sanitation and agriculture sectors. The session used the insights gained during the workshop field visit, which demonstrated two case studies:

- Wastewater treatment at the Aleppo Wastewater Treatment Plant followed by resource recovery downstream of Aleppo city for restricted irrigation
- Sewage from the towns of Sfireh and Tel Aran being discharged into an irrigation drainage channel with the potential for pollution of water sources. This mixed water was then used for irrigation prior to discharge into the Jabboul Lake, which is a protected saline wetland selected as a Ramsar site in 1998

The workshop participants were divided into groups and requested to address the following question: *What is it that could have been done or what is it that can be done better, from the perspective of different upstream and downstream stakeholders with an interest in wastewater recycling*? The groups were asked to give presentations in the form of a stakeholder dialogue, with participants in each group playing the role of the stakeholders.

The highlights of the discussions were that different stakeholders had different and diverging viewpoints, each of which was relevant to the particular stakeholder group. Some views were synergistic whereas others were diametrically opposed. The question then was: *How can these different viewpoints be reconciled to make wastewater recycling and resource recovery more effective*? The need for MSPs was introduced and described as follows:

- MSPs are the basis of processes that aim to involve stakeholders in improving situations that affect them
- MSPs are forms of social interaction, enabling different individuals and groups to enter into dialogue, negotiation, learning, decision making, and collective action.

It was revealed that linking the agriculture and sanitation sectors for better resource management entails dealing with: the water supply and sanitation sector; the agriculture and irrigation sector; health and environment agencies; local municipalities and city planners; and associated farming communities and others beneficiaries of wastewater. Schematically this can be represented as shown below (Figure 2).

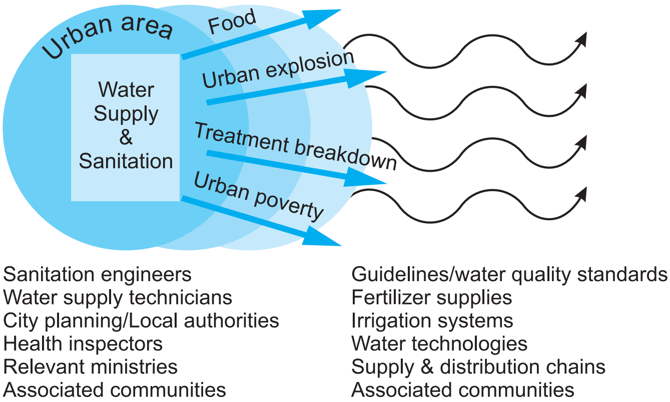

Fig. 2 Linking water supply and sanitation sectors for better resource management

Two examples of ongoing MSPs were discussed. The first example was an application by an MSP to facilitate the development of Urban and Peri-Urban Agriculture (UPA) in Accra, and to integrate it into the strategic plan and policies of municipal authorities and other relevant stakeholders. The outcome of the process was as follows: as an important source of urban food supply, the UPA was included in the Food and Agriculture Sector Development Policy II, leading to a revision of the bye-laws of the policy. It was also recognized in the National Urban Policy and the National Irrigation Policy of Ghana.

The main lessons learned were that such processes are slow and require a spearheading institution to initiate them. Regular consultations with stakeholders and capacity building of individuals and institutions are essential to gain commitment leading to long-term benefits from the process.

The second example was the application of the concept of learning alliances to encourage innovation in the design of solutions and effective scaling up. A learning alliance was presented as a series of connected MSPs at different institutional levels (national, district, community, etc). Its aim was to carry out innovation in an area of common interest, and to break down horizontal and vertical barriers to information sharing so as to speed up the process of identification, development, uptake and scaling up of innovations.

The session participants recognized that there is no standard recipe for making learning alliances operational. It was explained that various organizational forms are possible, that the structure would depend on needs and context, and that building upon existing institutional framework and networks in a given situation, was to be encouraged. In order to facilitate learning alliances that function effectively, it is important that:

- A comprehensive stakeholder analysis is undertaken to understand the representation needed in an alliance
- The alliance undertakes joint problem identification and definition, i.e. finding common ground and setting a common agenda for working on these problems through specific actions
- Information is fed back to learning alliance members within a cycle of action research in a relatively short time frame, i.e. 'short cycle dissemination'

Two applications of learning alliances were described. The first was in the Sustainable Water Management Improves Tomorrow's Cities' Health (SWITCH) project, a consortium of 32 partners from 13 countries carrying out research, training, and demonstrations to find sustainable solutions to urban water management. In a specific country context, the different levels of the learning alliances can be schematized as follows (Figure 3).

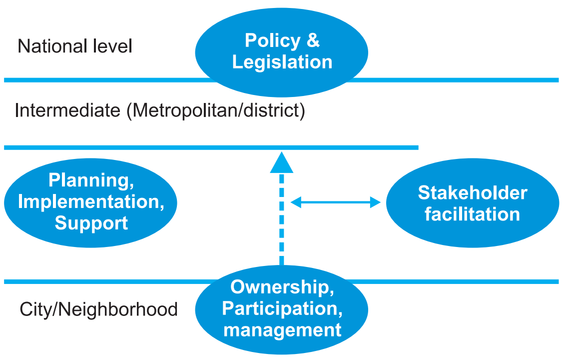

Fig. 3 The learning alliances for sustainable wastewater management

The learning alliance for the city of Accra, one of the demonstration cities of the project, has the following objectives:

- Sharing knowledge on urban water management across different sectors
- Linking activities in urban water management to increase effectiveness
- Linking planning across the urban water cycle
- Testing and implementing new technologies
- Leveraging activities and influencing through partnerships

The second application of learning alliances was in the Wastewater Agriculture and Sanitation for Poverty Alleviation (WASPA) project, with the following objectives:

- Finding innovative local solutions through joint learning
- Fostering dialogue between local government, NGOs, and associated community (empowerment)
- Ensuring buy-in from all stakeholders for sustainability
- Scaling up solutions to other locations (building ownership with some of the learning alliance members to take solutions forward)

This project tests solutions for sanitation and using decentralized wastewater management in agriculture. These are holistic solutions that focus on interventions in the chain of improved sanitation, contaminant reduction, promotion of hygiene behavior, and wastewater treatment, disposal, and use in agriculture. Stakeholders are involved in jointly developing and implementing participatory action plans to test technologies for safe waste management and application in agriculture.

Session 6 Social, economic and livelihood impacts of wastewater use in agriculture

Resource Person Heinz-Peter Wolff, University of Hohenheim, Stuttgart, Germany

Key message: Understanding and addressing the social, economic and livelihood impacts of wastewater use in agriculture assist in evaluating implications for the communities concerned as well as formulating policies and decision-making processes that lead to efficient use of water resources, particularly in water scarce environments.

With the aim of addressing the social, economic and livelihood impacts of wastewater use in agriculture, the session started with a presentation introducing the interdependencies that determine the socio-economic impacts of wastewater use. It was highlighted that the analysis and prognosis of the social and economic consequences of wastewater use require a system perspective. This comprises the actions and decision making of several interlinked stakeholders such as farmers, livestock holders, consumers, processing industries and traders. Furthermore, it takes into account the decisions and actions of other economic sectors competing for water of different qualities, as well as institutions involved in the relationship and management of water transfer between rural and urban areas. It became evident that a mere calculation of profits per ha or per unit of additional water is not a sufficient basis for decisions on the advantages or disadvantages of wastewater use. Advanced concepts on the technical and managerial setup of water chains - such as the 'reversed water chain approach' (Stimulating Session 1), which strives for a more holistic perspective on water quality management – demand for holistic socio-economic evaluation. Cost-benefit analysis may serve as a tool for comparing final flows of values, but is no replacement or shortcut for the required preceding analyses of basic parameters on: (i) living standards of individual families; (ii) quality of life, which includes living standards and the intangibles that influence peoples' decision making and well being; (iii) livelihoods, which focus on quality of life in the societal context.

Finally, the presentation made reference to contributions, observations and discussions that came up during the preceding days of the workshop. Major topics were: (i) the exclusive validity of socio-economic findings for a particular case under research; (ii) the impact of wastewater use on marketing and exports of products; (iii) the ambiguous role of fertilizing effects from nutrients in wastewater; and (iv) potential side effects on other inhabitants of areas using wastewater, such as livestock holders, landless families, and owners of real estate.

Following the presentation, the participants were grouped into four teams for a 30-minute discussion on expected socio-economic impacts from selected improvements in wastewater use, which were presented during the preceding sessions of the workshop. Focal points of the discussion were impacts on the basic parameters of farmers' living standards, such as income, cash availability, household supply, and uncertainty. The groups came up with the following salient observations.

- Group 1 addressed graywater management in north-eastern Badia, Jordan. The discussions revealed that applied solutions, such as septic tanks, intermittent sand filters, and the up-flow anaerobic sludge blanket (UASB), for treating graywater at the household level are technically efficient and if installed lead to quantifiable impacts on income, cash availability, and household supply. Reasons for this are the use of additional water and savings in water purchase. However, the advantages occur only under the conditions of (i) a strong participation of associated families in decisions on the set-up and use of the system, and (ii) substantial external support in the investment costs for the system.

- Group 2 focused on graywater treatment and reuse in Lebanon. The adapted 4-barrel-kit for purifying graywater is, like the approaches applied in the Jordanian Badia, a technically satisfying solution for individual households as it adds to income, cash availability, and household supply, while reducing the risks associated with an insecure external water supply. However, this holds only as long as costs do not exceed the level of usual maintenance. Initial investment costs for the system and irregular repair costs, in particular for the pump, may easily exceed the economic capacities of most families. Thus, the proposed solution to graywater treatment remains an option as long as installation and repair are provided from the outside, but may need additional financial solutions before it will become a self-spreading approach amongst the target groups.

- Group 3 discussed the cessation of irrigation and the use of a drip irrigation kit as methods for improving wastewater irrigation. The hygienic advantages of the drip irrigation kit may lead primarily to savings in costs for health and improved labor capacities in farming families. These effects may also occur with regard to the cessation of irrigation due to fewer contacts with contaminated water, but presumably to a lesser extent. Socio-economic difficulties are likely under conditions where there are: (i) lack of incentives from the market, e.g. higher prices, for products that are produced under hygienically favorable conditions; (ii) probable losses due to the early cessation of irrigation;

(iii) greater investment costs for the drip irrigation kit. Significant socio-economic benefits from the proposed methods will strongly depend on the development of consumers' awareness, provided that the latter translates itself into purchase decisions. Positive socio-economic impacts for health costs and the labor force may compensate only in specific cases for negative impacts on required investments and losses in market value.

- Group 4 discussed furrow irrigation and the use of composted poultry manure as approaches leading to improved wastewater management. The group revealed that hygienic advantages and their impact on socio-economic parameters of farming systems work in the same direction as the cessation of irrigation and use of the drip irrigation kit (Group 3). The same holds for the currently missing market incentives. In addition, costs, benefits and impacts on labor costs from furrow irrigation will depend not only on the appropriateness of the slope of farmers' fields but also on land scarcity, since furrow irrigation may demand more space per unit of plant population than irrigation with watering cans. In particular, consequences for cash availability from using composted poultry manure depend on the availability of stocking capacities and whether farmers produce such manure by themselves or buy it from external sources.

The joint discussion pointed out that the best approach to graywater treatment in a specific case will strongly depend on locally available expertise for constructing alternative water purification systems and economic competitiveness between alternatives with particular regard to their investment demands. Participation of the target group in raising awareness on hygiene and joint evaluation of the strengths and weaknesses of improvements were identified as major ingredients in the process of introducing new technologies to existing 'traditional' systems using graywater.

Under the given conditions, applying methods for safer use of wastewater provide potential benefits in farmers' health, labor capacity, and quality of life. Further incentives, which may be crucial for large-scale use of those methods, may arise predominantly through consumer awareness that translates into differences in purchasing behavior.

Session 7 WHO guidelines for wastewater and graywater use in agriculture: the basis for their revision, and future perspectives

Resource Persons Thor Axel Stenström, Swedish Institute for Infectious Disease Control, Solna, Sweden

Key message: Based on scientific consensus and the best available evidence along with consideration of national, socio-cultural, economic, and environmental factors, the revised WHO guidelines (2006) are designed to address the protection of health of farmers and their families, local communities, and product consumers, as well as beneficial use of scarce water resources.

Considering that about 10% of the world's population consumes crops irrigated with wastewater, the WHO has recently revised guidelines for wastewater and graywater use in agriculture. The revised guidelines provide different options for reaching an acceptable safety level, including wastewater treatments, irrigation practices, and post-treatment options. These guidelines also account for die-off of organisms in the field, where withholding periods can be applied between the last irrigation and the harvest period as additional safety precautions. Similarly, different treatment options and precautions are applicable for faecal sludge.

The revised guidelines are based on the Quantitative Microbial Risk Assessment (QMRA) approach, which includes a structured Hazard Assessment and Exposure Assessment. These inputs are further related to dose-response information, mainly based on published data. These are combined in risk characterizations and expressed either as 'risk per exposure' or yearly numbers of infections. Comparisons are often made with the endemic background level of disease.

Central questions to pose in the exposure assessment are: (i) What is the volume that individuals are exposed to? (ii) What is the likely frequency of exposure? (iii) How many people are exposed directly or indirectly? This can be applied in a structured assessment of the full handling chain from exposure in the wastewater treatment, through to exposure in outlet areas or in areas of reuse, like agriculture.

In the presentation given during the session, this assessment is exemplified in a stepwise approach for a wastewater treatment plant. In the approach, the local incidence of different diseases is accounted for as well as treatment variability. And, the different intentional and unintentional uses of water are accounted for as well as measures to limit exposure.

The number of yearly infections is related to the 'severity of hazards'. The latter can be defined in the local, regional or national context and does not have to follow the criteria used in this example. A classification of exposures is also made and related to different pathogens and exposure pathways. Control measures can be defined for the different exposures within the risk management framework, and where applied, will further lower the risks. The management strategies to reduce health risks are waste treatment, crop restrictions, waste application methods, and control of human exposure.

Several areas are less well covered and some need to be addressed in implementation strategies and future investigations; for example, additional comparative epidemiological studies, system assessment, cost-benefit analysis and links between behavioral factors, hygiene, and reuse aspects.

Technical Papers

Gray Wastewater Management: Sustainable Options for Crop Production in the East Mediterranean Region

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Abstract

The aim of this paper was to assess the role of gray wastewater reuse in sustainable water management in arid regions; it documents the experience of gray wastewater reuse in Jordan, Palestine, and Lebanon. Gray wastewater (GW) comprises 50–80% of residential wastewater and is used in groundwater recharge, landscaping, and irrigation. A case study on GW reuse in Jordan, Palestine, and Lebanon is presented to shed light on the role of GW in sustainable water management. The study concludes that current environmental policies should aim to control pollution and maximize GW recycling and reuse in households and communities. Decentralized GW management offers more opportunities for maximizing recycling opportunities.

Key words: Gray wastewater, East Mediterranean Region, intermittent sand filter, up-flow anaerobic sludge blanket reactor

1 Introduction

Water is essential for socioeconomic development; however, it is misused and wasted in today's society. Sound and sustainable management of water resources is crucial in arid and semi-arid regions (Al-Jayyousi 2003). Water balance in the East Mediterranean Region (EMR) has reached critical levels due to population growth, increased per capita water usage and decreasing supply (Al-Kloub and Abu-Taleb 1998).

Wastewater management is a continuing problem in many countries. The problem is acute in the EMR, particularly in rural areas where people lack public sewerage services and inhabitants in such clusters rely mainly on inadequately managed on-site wastewater disposal systems that do not protect scarce water resources, public health, and the environment. To address water scarcity, many EMR governments consider treated wastewater a strategic resource that should be managed and used to lower the stress on water supply. Moreover, gray wastewater (GW) – water from sinks, showers, and washing machines – is considered a component of wastewater, which is referred to as marginal-quality water (Nolde 1999).

Gray wastewater reuse is based on the closed-loop concept, implying that it is managed and reused in a decentralized manner within the household, neighborhood, and community. The main idea of the closed loop is to match water quality with appropriate water uses, i.e. GW may be allocated for uses such as irrigation, landscaping, toilet flushing, and groundwater recharge.

The significance of this research stems from the fact that GW is about 50–80 % of wastewater (Surendran and Wheatley 1998). Hence, if GW could be collected, treated, and utilized, then stress on water resources and wastewater treatment plants will be reduced. GW reuse helps support the sustainability of valuable freshwater resources. GW treatment could save 25–40% of drinkable water for consumption (Coder 1999).

2 Gray wastewater in the East Mediterranean Region (EMR)

2.1 Gray wastewater in Jordan

Royal Scientific Society (RSS) – Environmental Research Centre Experience
The research project 'Integrated Wastewater Management Technologies and Policies for Marginal Communities in Jordan' was implemented in the small rural communities in the northeastern *Badia* of Jordan by the RSS. The project was funded by the International Development Research Centre (IDRC) of Canada. The project targeted 33 small communities scattered over five municipalities of total area 25,600 km^2 (Department of Statistics, 2002). These communities lack public sewerage services and any GW management structure. The inhabitants rely on inadequately managed cesspools for blackwater, open disposal of GW in the surrounding environment, and uncontrolled reuse of GW for irrigation. Moreover, they have no clear organizational set-up to plan, implement, and manage GW resources in coordination with water services that considers community needs and requirements.

In close consultation, and active community participation, the project investigated the feasibility of adopting innovative, non-conventional GW management policies for marginalized, small rural communities in the northeastern *Badia*. This was approached through a coherent framework of activities including integration of various components of social, technical, economic, environmental, institutional, and public participation requirements. The research project was completed in 44 months in four main phases. Phase I was a preparatory phase when the project team was formulated, a start-up workshop was organized, and participatory rural appraisal training and field visits were conducted. In Phase II, participatory development communication tools were used to collect and analyze information, understand issues, challenges, and problems related to wastewater and GW issues from a wide range of stakeholders in a variety of ways; two communities were selected as research project sites. Phase III included activities related to selection and design of a community-based integrated GW management system, training, and institutional strengthening/capacity building. Phase IV included evaluation, reporting, and a wide range of dissemination activities.

The RSS worked in close cooperation with local governmental institutions, non-governmental organizations (NGOs), and community-based organizations (CBOs) on the research project. The RSS team, as well as NGOs and CBOs, used participatory tools and methodologies to design and implement various project activities, where the participatory components can help ensure the success of the project at various stages of implementation.

The early involvement of local people and different stakeholders in project activities enhanced the quality of work and supplemented the scarce information and data, while ensuring project sustainability. The GW in the northeastern *Badia* of Jordan was found to be strongly polluted and needed quality improvement at source before disposal to the treatment unit. Moreover, it was found that a septic tank followed by an intermittent sand filter and an up-flow anaerobic sludge blanket (UASB) reactor could both successfully treat this GW. The performance of the treatment units was assessed by testing the quality of the raw GW and the treated GW discharged from the units. For assessment purposes, composite GW samples were collected weekly from the influent and effluent of the septic tank/intermittent sand filter and the UASB pilot units (Table 1). Samples were analyzed for EC, TSS, BOD_5, COD, Fat-oil-grease (FOG), methylene blue active substances (MBAS), total N, total P, and *Escherichia coli*.

Further work is needed to recommend governance structure and to frame an approved policy for GW management in these small rural communities. It is anticipated that the direct beneficiaries of the project will be local people, who have their own household agriculture, since they usually purchase freshwater from private tankers. In the project area, 72% of local people cultivated olive trees in their household gardens. There were 7768 olive trees in the project area, with an average of 38 trees per household (within the

Table 1. Performance of septic tank/sand filter and up-flow anaerobic sludge blanket (UASB) systems

Parameter	Unit	Septic tank/intermittent sand filter			UASB unit		
		Influent	Effluent	Efficiency (%)	Influent	Effluent	Efficiency (%)
COD	mg L^{-1}	1952	312	84	1702	592	65
BOD_5	mg L^{-1}	1149	135	88	916	305	67
TSS	mg L^{-1}	606	55	91	524	142	73
Total N	mg L^{-1}	112	49	56	20	16	20
MBAS	mg L^{-1}	27.2	16.5	39	25.3	9.2	64
Total P	mg L^{-1}	15.2	9.9	35	7.7	5.1	34
E. coli	MPN $100mL^{-1}$	1.3×10^6	3.6×10^2	**	1.2×10^8	2.1×10^7	**
FOG	mg L^{-1}	196	< 8	96	70	19	73

sample that grew trees). Almost 36% of people growing olive trees previously bought water at a monthly average cost of 9 JD/4 m^3 (US$ 13) to irrigate trees; an additional cost of about 10% of their income. The average GW generated was about 150 L per day or 4.5 m^3 per month; this amount of water would compensate for the need for water tankers and save a household US$13/month. For those who use tap water to irrigate trees, the quarterly water bill would be reduced by 3.75 JD (US$ 5.40). GW reuse will also contribute to food security (olive fruit and oil) and add to household income, by saving irrigation water costs and by sale of olives and olive oil.

The study helped conserve scarce water resources and improve water use efficiency by promoting treatment and reuse of GW. It contributed to improving the quality of life of the small rural communities in water scarce regions by building their capacity in wastewater and GW issues. The project also empowered local people to define their problems, assess their needs and requirements in GW management, and reinforce their feeling of responsibility and ownership for the GW management systems that they chose and worked on. Moreover, it increased public awareness and community know-how in fields of GW management and reuse.

Inter-Islamic Network on Water Resources Development and Management (INWARDAM) Experience

IDRC provided financial assistance to an applied research project on GW treatment and reuse for home garden irrigation in 25 low-income households in Ein Al Beida village in southern Jordan. The main objective of the project was to help the peri-urban poor in Jordan, preserve precious freshwater, achieve food security, and generate income, while helping to protect the environment. The average family size was 6.2 persons and daily domestic water consumption (including garden irrigation) averaged 120 L per person.

INWARDAM used several systems for GW treatment. The most effective was the horizontal flow filter treatment unit, which consisted of a settling tank, a trench filled with gravel, and a storage tank. The trench (3 m × 1 m × 1 m) was lined with impermeable polyethylene sheet (400-500 μm thick) and filled with 2-3 cm diameter gravel. Pre-treated GW from the settling tank enters the horizontal filter at the bottom and flows through the filter media where anaerobic conditions prevail. At the other end of the trench, a perforated 120 L barrel functioning as a storage tank is buried in the filter bed. Table 2 shows the effluent analysis of treated GW in Ein Al Beida, Jordan.

Table 2. Performance of horizontal flow filter unit at Ein Al Beida, Jordan

Parameter	Unit	Influent	Effluent
BOD5	mg L^{-1}	1500	171
TSS	mg L^{-1}	316	204
Oil and grease	mg L^{-1}	141	–

The project had several direct and indirect benefits for the community and the environment. Women benefited most from this project through training workshops, dialogue, and learning-by-doing. Further knowledge was acquired on building a productive garden as well as general management skills. The monthly domestic water bills decreased by about 30%, and many families were able to reduce their food expenses by consuming the fruits, vegetables, and herbs produced in their home gardens. In addition, about one third of households generated income by selling the surplus (Faruqui *et al*. 2003).

2.2 Gray wastewater in Palestine

Septic Tank-Upflow Gravel Filter plants were constructed by the Palestinian Relief Committees (PARC) for treatment of GW from one up to 30 houses, with 7–20 inhabitants per house. PARC constructed about 300 household treatment plants and seven collective treatment plants. Some of these systems started working in January 1997, receiving GW flows of 500–20000 L d^{-1}. After treatment in multi-layer aerobic filters, the effluent is mostly used in drip irrigation systems for home gardens. In GW, the COD concentration was very high (~1270 mg L^{-1}) and nitrogen was mainly in the form of nitrate (38 mg L^{-1}). COD removal efficiency of 70-88% was always achieved after about 25 d from starting the treatment plant. The effluent was almost free of fecal coliforms (Burnat 1997). Therefore, the GW treatment in Septic Tank-Upflow Gravel Filter plants and effluent reuse in unrestricted agriculture has high potential for environmental protection, water conservation, and food security.

2.3 Gray wastewater in Lebanon

With funding from IDRC, the Middle East Center for the Transfer of Appropriate Technology initiated a GW treatment and reuse project in

Tannoura, Lebanon. The project aimed at reusing treated GW, as an available resource that was not yet utilized and with potential to provide irrigation water, in addition to boosting crop production in backyard gardens. This project benefited 30 houses in Tannoura. Each house was equipped with a four-barrel treatment kit that anaerobically treated the collected GW in 1–2 d, which was then pumped into a drip irrigation network in the garden (EAWAG 2006).

The project was not only scientific research, but also had a participatory social and educational component to improve the residents' quality of life. Women were empowered through several training and decision-making activities. The success of the GW project in Tannoura and nine other towns in the Rashaya district in which the project is implemented, would encourage the government to adopt smaller GW projects, simple to implement and with results felt at household and community levels.

3 Conclusions

Gray wastewater reuse is an option for water demand management and also contributes to reducing use of freshwater for irrigation. To ensure water sustainability, GW reuse needs to coincide with garden design and growing food at home and public open spaces. The following conclusions can be drawn: (i) GW quality varies considerably and appropriate technology should be selected to suit the users' needs and to utilize local knowledge; (ii) Septic tank followed by an intermittent sand filter, horizontal flow filter, and Septic Tank-Upflow Gravel Filter are considered the best solutions for GW treatment; (iii) Communities should be involved in GW management processes to ensure sustainability; (iv) Treated GW could be used for olive and other fruit trees and can contribute to the country's food security.

Acknowledgments

The author gratefully acknowledges the International Development Research Center, Royal Scientific Society, and Inter-Islamic Network on Water Resources Development and Management for their key role in GW management development in EMR countries.

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Meeting the Dublin Principles in Graywater Management in Rural Communities in the Northeastern *Badia* of Jordan

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Abstract

The main objective of this paper was to document the experience of the Royal Scientific Society in the integrated management of graywater in Jordanian rural communities. This paper presents interim results of an ongoing project and illustrates the extent of conformity to the water management principles adopted at the International Conference on Water and the Environment in Dublin in 1992. Several meetings were held with community members in the project area and a Local Stakeholder Committee (LSC) of the community members at all levels was formed. Several field visits to wastewater treatment and reuse projects were organized for LSC and other community representatives. A training workshop that targeted LSC and other community members, and focused on Participatory Rapid Appraisal tools and methodologies was conducted. Public awareness campaigns were undertaken by an NGO working in the project area. Graywater quality and quantity generated by six households in Abu Al-Farth village were investigated to evaluate the feasibility of reuse for irrigation and to assess treatment requirements. The daily graywater generation rates were 150–200 L per family. Organic contents, solids, and *E. coli* levels were relatively high, as were macronutrients. On-site treatment units (a septic tank followed by an intermittent sand filter) were constructed and began operating in March 2006; providing reclaimed water for restricted irrigation. The study showed that following the Dublin principles (saving freshwater, adopting participatory approaches, enhancing gender issues, and viewing water as an economic good) in water management even in small cases would ensure sustainability and successful management.

Key words: Dublin Principles, integrated water resources management, graywater quality, graywater quantity, rural communities

1 Introduction

Scarcity and misuse of water are serious and growing threats to sustainable development and protection of the environment. Human health and welfare, food security, industrial development, and the ecosystems on which they depend are all at risk, unless water and land resources are managed more effectively than they have been in the past (Al-Jayyousi 2003).

At the International Conference on Water and the Environment in Dublin, Ireland, on 31 January 1992, there were 500 participants including government-designated experts from 100 countries and representatives of 80 international, intergovernmental, and non-governmental organizations. This conference produced four principles for effective and sustainable water management: (i) freshwater is a finite and vulnerable resource, essential to sustain life, development, and the environment; (ii) water development and management should be based on a participatory approach, involving users, planners, and policy-makers at all levels; (iii) women play a central part in the provision, management, and safeguarding of water; and (iv) water has an economic value in all its competing uses and should be recognized as an economic good (Solanes and Gonzalez-Villarreal 1999).

Jordan's population was estimated at 5.2 million in 2001 (Dept of Statistics 2002), approximately 78% rural and 22% urban. People in small-rural communities are located in about 1145 clusters scattered over the country (Table 1). These communities lack public sewerage services, and the inhabitants rely mainly on inadequately managed on-site wastewater disposal systems. These systems do not protect scarce water resources, public health and safety, and the surrounding environment because of the discretionary manner in which they were designed, installed, and managed.

Table 1. Jordan's population distribution in 2001 (Dept of Statistics 2002).

Population range	Number of communities	Population
> 50,000	17	1,888,500
10,000-50,000	91	1,740,700
5,000-10,000	81	532,140
< 5,000	1145	1,020,660

The country is facing a future of very limited water resources, among the lowest in the world on a per capita basis (Faruqi and Al-Jayyousi 2003). Although access to safe drinking water is impressive, reaching > 96% of the population, expansion of modern sanitation systems to meet public health and environmental goals has lagged significantly behind, particularly in marginalized rural areas. This is mainly attributed to current wastewater management policies that rely on centralized systems, hampering the extension of this service to small, rural communities where dwellings are scattered over large areas. There is increasing interest in adopting non-conventional wastewater management strategies for small communities that have not been provided with sewerage system in Jordan; however, this has not been investigated. This paper presents interim results of an ongoing project and illustrates the extent of conformity to water management principles as adopted in Dublin in 1992.

2 Methods

2.1 Project area

The project area is the northeastern *Badia*, an area of 25,600 km^2 that is 28% of Jordan's area, with a population of 28,480 living in 35 clusters in 2003. The word *Badia* means the place where *Bedouin* people live. In the past the *Bedouin* were more nomadic than today. In recent times their lifestyle has become more stable, with more demand on infrastructure, facilities, and services.

2.2 Community participation

Site visits were organized to most communities in the project area. Meetings were held with community leaders and representatives, municipality directors, school managers, and representatives of Non Governmental Organizations (NGOs) and Community Based Organizations (CBOs) to introduce the project idea, objectives, work methodology, and the community's role.

The communities formed a voluntary Local Stakeholder committee (LSC) that comprised 15 persons (4 females and 11 males) from different communities in the project area. A head and a secretary were elected to facilitate communication with the public, and to document feedback from the communities and minutes of meetings. The LSC was involved in various project activities. The researchers met regularly with the LSC to discuss project issues, including technical aspects.

To build capacity among the public on different aspects of participatory development communication, the research team designed and implemented a training workshop for four days at a CBO in the project area. The training focused on the concept of participation, Participatory Rapid Appraisal (PRA) tools, and methodology to identify wastewater problems and solutions based on the community's perspectives and needs. The emphasis was on the more salient issues such as inhabitants' perceptions about water scarcity, graywater reuse at the household level, and on-site wastewater management practices. The PRA tools included semi-structural dialogue, ranking, maps, seasonal calendars, daily routine analyses, and direct observations.

To enhance and ease community involvement in different project activities, a Memorandum of Understanding was signed with a CBO working in the project area, by which CBO staff conduct some project activities. A meeting room was provided by the CBO for regular meetings with the public and LSC members.

2.3 Data collection using PRA

Utilizing information learned throughout the PRA training workshop, the researchers and the LSC prepared a checklist to identify social, economic, environmental, and technical issues related to the study based on community's perspectives and needs. The checklist was used to guide the team in collecting data during field visits to the families.

A work plan covered the project area, taking into consideration that 8-15% of the population need to be included in data collection. Work teams were formulated, each consisting of 3-5 members that included at least one female and one of the research team. One member was assigned to lead the semi-structural dialogue, another for documentation, and a third to taking site-direct observations, while a female team member met with housewives. Each work team was assigned a study area, with a minimum number of meetings to be conducted. There were 404 meetings during 13 days of fieldwork. Upon completion of the fieldwork, the group met daily to discuss major findings.

2.4 Public awareness

A public awareness program was implemented that had three major components targeting community members at all levels in the project area, including women, men, housewives, and school students. The first component included scoping sessions with community leaders. The main objective was to brief the audience on major environmental issues and problems in the project area with special emphasis on topics related to the research project, e.g. water scarcity; water pollution, causes, and solutions; wastewater management, treatment, and reuse; water use patterns at the household level; water conservation; and graywater reuse for backyard irrigation. As part of the second component a contest was held for the best environmental drawing, which targeted school students exclusively, as school students are about 25% of the population in the project area. About 230 students participated, the drawings were screened, and seven drawings selected as the best. These seven drawings were included in a poster designed, printed, and distributed in the project area. The third component comprised lectures and workshops targeted at school teachers (female and male), health and public safety inspectors, school students (female and male), housewives, and other community members. Issues related to water scarcity, water conservation and graywater reuse for irrigation were emphasized.

2.5 Identification of an appropriate community

The following criteria were used to identify a community within the project area as the research site for field pilot-experiments, based on selecting an appropriate treatment and reuse system in close consultation with the community and the LSC:

- Opportunity to improve current wastewater management practices
- Social acceptance and willingness to reuse graywater
- Representativeness and potential for replication
- Institutional support and presence of NGOs and/or CBOs

The researchers reviewed the data and information collected to screen the communities, and site visits to communities were organized with the LSC. The group identified Abu Al-Farth as the research project site.

2.6 Graywater quality and quantity

There were three modes of collecting graywater generated by households at the research site:

- Collecting all graywater at one discharge point
- Collecting water from the kitchen at one point, and other graywater sources (bathing, floor washing and mopping, laundry, and others) at another point
- Collecting water from the kitchen at one point, water from ablutions and handwashing at a second, and other graywater sources at a third point.

Quality and quantity of graywater discharged at different points were investigated during March to June 2005 in six households (two each followed the same trend of graywater separation) selected in cooperation with the LSC (Table 2). There were some modifications to the discharge system to facilitate measuring quantities and collecting samples for analysis. Generated quantities were measured daily, while composite samples were collected bi-monthly from each discharge point.

Table 2. Six households and graywater sources.

Site code	Graywater source	Notes	Dwelling no.
A B	Kitchen sink only Other than the kitchen sink	Seven-member family with one child. Indoor toilet. No shower.	1
C	Total graywater	Seven-member family with three children. Pit latrines. No shower.	2
D	Total graywater	Nine-member family with three children. Pit latrine. With shower.	3
E F G	Other than kitchen and ablution sink Kitchen sink only. Ablution and hand washing	Nine-member family with one child. Pit latrine. No shower.	4
H I J	Kitchen sink only Other than kitchen and ablution sink Ablution and hand washing	Eleven-member family with three children. Pit latrine. With shower.	5
K L	Kitchen sink only Other than the kitchen sink	Five-member family with three children. Pit latrine. With shower.	6

2.7 Watershed quality assessment

During March to June 2005, water samples were collected from surface water, groundwater, and water used domestically in six households in Abu Al–Farth. These were analyzed for physical, chemical, and microbial properties to assess quality and suitability for anticipated uses.

2.8 Formulation of a local women's committee

To encourage women's participation in fields related to the research project, a women's committee was organized in Abu Al-Farth. The committee consisted of six active and committed women who strongly believed in the importance of managing graywater practices to develop their community. This was aimed at enhancing awareness of graywater management issues among local women. The project team met regularly with the committee, to introduce some hygienic practices that enable production of less contaminated graywater, and use of environmental-friendly detergents. The committee visited graywater collection and sampling activities in Abu Al-Farth. Women gave their perceptions of the environmental conditions of the tanks, such as the presence or absence of odors and cleanliness.

2.9 Selection of appropriate treatment systems

An expert group consisting of the research team, local wastewater treatment and reuse experts, and LSC representatives was formed in September 2005. The main objective of group was to establish a network for discussion, information exchange, assessment and evaluation of affordable and attractive options for graywater treatment that were suitable for the local environment/social conditions, and to develop feasible, cost effective, and technically sound approaches for graywater treatment and reuse in the project area. The experts recommended utilizing one or more of the following treatment options, taking into account the socioeconomic aspects of the study area and feedback from the LSC representatives: (i) up flow anaerobic sludge blanket; (ii) septic tanks followed by intermittent sand filter.

2.10 Installation of a greywater treatment unit in one household

To treat graywater and reuse for restricted irrigation, an on-site treatment unit (septic tank and intermittent sand filter) was constructed, in close consultation and with active community participation. It began operating in March 2006.

2.11 Reuse of reclaimed water

Treated graywater has been utilized for irrigation of specific crops, such as olives, forages, and some fruit trees. Graywater reuse helps support the sustainability of valuable freshwater resources.

3 Results and discussion

3.1 Social, economic, and environmental information

Total population of the project area was estimated at 28,480 in 2003, in 35 small clusters. Females make up 50.2% of the population. The society is characterized as 'youthful' with > 40% less than 15 years age. The average family size is 9 persons, and about 18.5% of the population is illiterate. The average per family monthly expenditure is estimated at 190 Jordan Dinar (JD) (1 JD = 1.41 US$ in November 2008).

The project area suffers a water shortage problem. Domestic water is supplied through the public network only 24 hours per week, and inhabitants purchase water from private water tankers, particularly in summer. People spend 5% of their income on water. Agricultural activities in the area are limited and are only possible through irrigation; wheat and barley are the main crops. The main obstacle to agriculture in the area is water scarcity.

The communities rely mainly on unlined cesspools for on-site wastewater collection. Cesspools are rarely emptied at some clusters, and others are pumped out monthly at an average cost of 21 JD per time. The closest legal liquid-waste dumping site is 80 km away, and inhabitants believe that wastewater pumped from cesspools is illegally dumped in nearby streams.

About 62% of the public in the project area utilize pit latrines or ventilated improved pit latrines, 33% have traditional (no-flush) indoor toilets, while only 1% use flushing toilets (compared with 89% at the national level). Only 40% of the community has showers and kitchen sinks.

Two-thirds of the community already separate graywater from blackwater, mainly for religious reasons. They consider that graywater is clean and can contain food remains (godsend) that must not be mixed with blackwater. Untreated graywater is directly reused to irrigate backyards in an uncontrolled manner, with no regard for health aspects.

3.2 Graywater quality and generation rates in 2005

During March to une 2005, generated graywater quantities at the six studied dwellings were measured daily. Some relevant information was also collected, such as number of family members, number of children, type of toilet, and whether they have showers and/or basins. In addition, composite samples were collected bi-monthly and analyzed for physical, chemical, and microbial constituents.

Generation rates were 11.9–18.7 L per person per day. Kitchens produced about 50% of the total generated greywater generated while ablutions and hand washing generated the least graywater of all activities. The highest generation rate was for the household with an indoor toilet, the other five households had pit latrines (outdoor toilets). There were lower generation rates for households without both showers and basins for bathing.

The graywater quality varied greatly from the same sources in different households (Table 3). This was mainly attributed to different activities undertaken during sampling (washing clothes, washing floors, and others). Organic content (BOD_5 and COD) and TSS levels were higher than expected. Levels were higher for households with more children. One practice in such communities is that diapers are not used for children, and it is common to clean children in sinks that lead to graywater discharge points. It is also common for inhabitants to wash their hands in the ablution or kitchen sinks after going to the pit latrines or toilets. Microbial levels (*E. coli*) were also higher than expected even for graywater from kitchen and ablution sinks, mainly due to the above-mentioned factors. The fats, oil and grease

Table 3 Characteristics of graywater sampled from different sites. The details of site codes are given in Table 2.

Para-meter	**Unit**	**Site code**											
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
pH	-	5.5	7.3	5.8	7.2	7.0	5.7	5.6	8.3	7.3	5.4	6.9	8.2
EC	µS/cm	870	2422	875	2373	2100	1560	1357	2812	1286	1163	859	2496
TDS	mg L^{-1}	649	1409	821	1724	1140	1007	918	1271	793	934	567	1138
TSS	mg L^{-1}	655	1789	527	1569	700	990	410	698	810	985	448	558
BOD5	mg L^{-1}	827	1285	832	1423	977	1134	1092	650	657	1648	544	716
COD	mg L^{-1}	1852	3202	1930	5501	2257	2878	2085	1915	1543	3109	1063	1745
Total N	mg L^{-1}	31	186	33	90	161	94	80	177	75	58	33	200
Total P	mg L^{-1}	32	25	9	25	16	23	13	34	25	19	18	29
K	mg L^{-1}	9	21	10	7	27	21	6	11	20	17	11	31
MBAS	mg L^{-1}	46	77	88	207	45	33	36	43	53	51	12	54
E. coli	MPN/100 mL	2.5×10^{5}	1.7×10^{5}	6.6×10^{4}	1.0×10^{6}	3.9×10^{4}	2.8×10^{5}	1.9×10^{4}	4.7×10^{4}	2.3×10^{4}	2.5×10^{6}	7.2×10^{3}	6.4×10^{5}
B	mg L^{-1}	0.8	0.8	0.6	0.7	1.0	0.7	1.7	1.6	1.0	0.6	0.4	0.6
FOG	mg L^{-1}	124	257	226	405	202	319	147	164	91	85	84	67

(FOG) content was higher than in the wastewater of other communities, particularly urban ones, and could be due to food type and meal patterns.

Organic content was higher for graywater from kitchens than from other sources. Levels of macronutrients (total nitrogen, TN; total phosphorous, TP; and potassium, K) were lower for water from kitchen and ablution sinks than from other sources. The pH of graywater collected from kitchens was lower than that from other sources. The methylene blue active substances (MBAS) ranged from 12 to 207 mg L^{-1}.

3.3 Graywater treatment performance of septic tank and sand filter in 2006

Septic tank followed by intermittent sand filter was constructed in one household in Abu Al Farth village. The septic tank followed by sand filter was very effective in treating greywater. The performance analysis of the system (Table 4) carried out in March-May 2006 shows that the treatment unit is effective in removing organic matters, suspended solids, detergents and pathogens indicated by *E. coli*.

Table 4. Performance of septic tank followed by sand filter in Abu Al-Farth

Parameter	Unit	Raw graywater	Effluent from dosing tank	Effluent from sand filter	Septic tank efficiency (%)	Sand filter efficiency (%)
BOD_5	mg L^{-1}	1181.67	480.25	67.50	59	86
COD	mg L^{-1}	2248.00	862.43	143.43	62	83
TSS	mg L^{-1}	608.75	199.86	37.00	67	81
FOG	mg L^{-1}	182.90	8.00	8.00	96	0
MBAS	mg L^{-1}	26.73	51.51	22.45	**	56
NO_3-N	mg L^{-1}	46.50	3.29	0.75	93	77
NH_3-N	mg L^{-1}	52.71	111.00	39.25	**	65
Total N	mg L^{-1}	121.28	111.50	34.00	8	70
Total P	mg L^{-1}	26.9	16.4	5.3	39	68
SAR	-	6.7	5.9	3.8	12	**
K	mg L^{-1}	27	32	21	**	34
B	mg L^{-1}	0.302	0.569	0.391	**	31
E. coli	MPN/100 mL	6841	4420	64	35	99

** No removal occurred

3.4 Meeting the Dublin Principles in project activities

Principle 1: Freshwater is a finite and vulnerable resource, essential to sustain life, development, and the environment. There were three aspects related to this principle, including (i) public awareness campaigns showed the public the importance of drinking water resources and the necessity to prevent losses and pollution; (ii) treated graywater reuse reduced overall water consumption especially for irrigation; (iii) availability of treated graywater in good quality and quantity for irrigation would encourage the public to investigate agricultural activities and enhance local development.

Principle 2: Water development and management should be based on participatory approaches, involving users, planners, and policymakers at all levels. In this case, themes of participation took place in the management process of the wastewater resources in the *Badia* including participation of local communities, governmental authorities, and scientific experts. The stakeholders participating in the management process of the wastewater include different levels of local people (men, women, students, and teachers), community leaders, religious leaders, NGOs, CBOs, decision makers, scientific experts, and governmental representatives. The role of the local communities was to determine their wastewater-related issues, to collect and analyze social, economic, environmental, and technical data related to wastewater issues, and promote the local wastewater management practices (separation and reuse of graywater).

Principle 3: Women play a central part in the provision, management, and safeguarding of water. There were two aspects related to this principle, including (i) women had a leadership role in promoting their local knowledge of wastewater management (separation and reuse of graywater) within their neighborhood and villages; (ii) a women's committee was formulated in Abu Al-Farth to enhance awareness of graywater management issues among local women, as well as playing a leadership role in following up on issues regarding the graywater treatment unit.

Principle 4: Water has an economic value in all its competing uses and should be recognized as an economic good. Treated graywater – as a water resource in the Abu Al-Farth area – is used to irrigate olive trees, but efforts are now concentrated on use for forage crops.

4 Conclusions

Based on the project-led activities and results, we conclude that local knowledge should be recognized and participatory approaches applied when investigating integrated water-resource management for small communities. However, intensive awareness campaigns are also necessary. Graywater is a vital and sustainable water resource that should receive considerable attention when targeting wastewater management in small communities. However, the quality and appropriate treatment systems need to be carefully investigated, taking public acceptance into consideration. The study reveals that following Dublin principles (saving freshwater, adopting participatory approaches, enhancing gender issues, and viewing water as an economic good) in water management even in small cases can ensure sustainability and success of management processes.

Acknowledgments

This research was conducted under Grant number 101954 from IDRC, Canada. The authors appreciate the support of Dr. Lamia El-Fattal, Senior Program Officer at IDRC. Grateful acknowledgement is made to Engineer Othman Mashaqbeh and Engineer Ahamd Swalha who participated in some research activities of the project.

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Survey on Wastewater Irrigation with Emphasis on the Nakivubo Drainage Channel in Kampala

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Abstract

Sources of wastewater used for irrigation in Kampala city were identified. Not all urban irrigation relied on raw wastewater, i.e. it is misleading to consider wastewater as a uniform commodity, since dilution by mixing means that irrigators use a range of water qualities. The major objective of the study was to understand the use of wastewater irrigation in Kampala and assess health risks involved and how this practice enhanced livelihoods. Urban wastewater irrigation cannot be viewed as a simple activity involving uniform characteristics and open to a standard response from planners, policy makers or technologists. Hence, there is a need for recognition and regulation of this practice by city authorities and government.

Key words: Informal wastewater irrigation, irrigation methods, wastewater sources, Uganda

1 Introduction

The use of urban wastewater in agriculture is growing with increasing scarcity of freshwater, especially in cities and other congested areas. Rapid urbanization and growing volumes of wastewater have made wastewater a low-cost alternative to conventional irrigation water; it supports livelihoods and generates considerable value in urban agriculture, despite health and environmental risks (Cornish *et al*. 1999, 2001, Hide *et al*. 2001). In Kampala this practice is largely unregulated, since it is commonly used in floriculture and nursery farming for seedlings along open drainage channels.

The National Environment Management Authority (NEMA), in collaboration with the Ministry of Health, has attempted to assess the risks involved in using wastewater in Kampala, but the risks are still unknown. The city authorities pay little attention to this practice since the bulk of its products are not directly consumable, e.g. floriculture and seedlings. However, NEMA is leading a debate on the levels of risk involved for individuals and communities in using wastewater.

The study examined the informal practice of irrigation with wastewater from open drainage channels. During the survey, other sources of irrigation water were found: piped water commonly used in vegetable fields; mixtures of pipe and sewerage water; tankers transporting water from lakes; treated main sewerage, water pools, protected springs, and wells.

2 Water quality and health risks in use of wastewater irrigation

An earlier study by NEMA and the Ministry of Health found that the mean fecal coliform count in wastewater did not exceed the World Health Organization (WHO) Health Guidelines for Use of Wastewater in Agriculture and Aquaculture. However, a broad recommendation from the Ministry of Health was that wastewater irrigation poses a substantial health risk to irrigators and the consumers of their farm produce.

3 Types of wastewater irrigation in Kampala

The Nakivubo channel flows through Kampala city, and is fed with wastewater from Katanga, Kivulu, Kiseka market, main taxi parks, Owino market, downtown Kampala city, and the main industrial area (after some treatment). The main user is JK Florist Ltd, a local farming group growing a wide range of flowers and tree seedlings for sale; mainly roses and seedlings of a variety of species such as fruit trees (e.g. mangoes, avocadoes, and oranges), pine, eucalyptus, neem, shade trees, and flowers for gardening. The company has three main plots and several other adjacent plots.

We also surveyed the Bugolobi farmers' group, whose number varies around 75 to 100 from season to season. On individual plots of mainly reclaimed swampland, they grow a range of crops, including tomatoes, onions, cabbages, carrots, beans, yams, flowers, fruit, and seedlings. The sources of irrigation water are provided in Table 1.

Table 1 Sources of irrigation water in sampled farming groups in Kampala

Source of irrigation water	Use (%)	Crops
Open stream (domestic and industrial waste) untreated	38	Vegetables, floriculture, tree nurseries, yams, maize, and beans
Treated/dilute wastewater	20	Vegetables, floriculture, tree nurseries
Mixed wastewater and pipe water	27	Vegetables, floriculture, tree nurseries, yams, maize, and beans
Water tankers/trucks	4	Grassed compounds and flowers
Other (e.g. pool, deep well, and main sewerage)	11	Flowers, vegetables, and tree nurseries

A range of factors determine the nature of wastewater irrigation in Kampala (Figure 1); the only non-physical factor considered was whether irrigation was in a formal (authorized) or informal (unauthorized) setting. Figure 1 does not include the wider social, economic, or institutional factors that influence the practice, although these are recognized as having an important influence on irrigators' behavior.

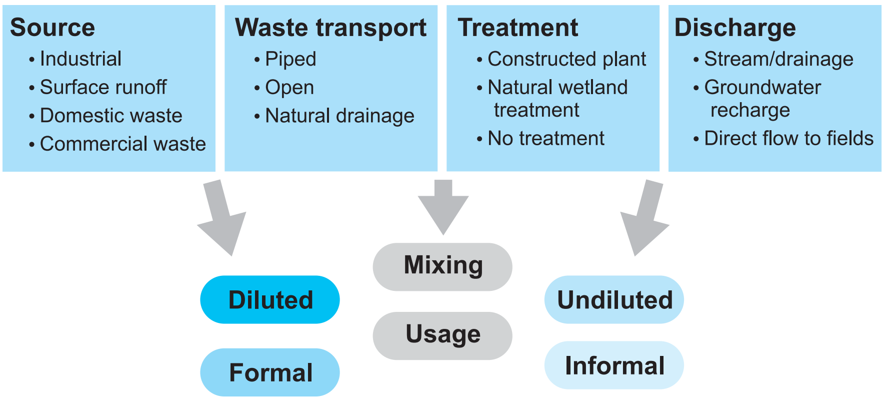

Fig. 1 Wastewater in Kampala from source to discharge

4 Rationale for using wastewater irrigation in Kampala

In this study, it was realized that the use of wastewater for irrigation in Kampala is seen to be a necessary technique that supports farming and enables essential crops to be grown, especially during dry seasons. This has led to increased productivity and cropping intensity, favoring crop diversity in the city; hence, a large variety of techniques have been developed for wastewater irrigation management.

Traditional watering methods were evident in farmers' practices. Pressurized irrigation techniques were common, and great effort is put into piping and pressurizing water through various sorts of sprinklers (Table 2).

Table 2 Range of irrigation delivery methods in Kampala

Method	Usage (%)
Pressurized (motor sprinklers)	28
Pressurized (manual sprinklers)	41
Traditional (buckets and watering cans)	26
Others	5

5 Contribution of urban wastewater irrigation to livelihoods of irrigators

Source of income. The seedling business runs throughout the year with average sales of 200 seedlings per day. Given that a seedling costs Uganda shillings 2000–3000 depending on type, the average daily income is Uganda shillings 400,000–600,000 (US$ 300–500).

Source of food. This is the case for the Bugolobi farmers' group, which grows a variety of food crops. The bulk of its produce is consumed locally; however, some crops, especially vegetables, are sold to the nearby markets.

Improving the environment. JK Florists Ltd prides itself in its input to improving the environment through the provision of seedlings to national tree growing campaigns. Using wastewater enables sustainable use of land and water.

6 Conclusions

The survey found that wastewater is commonly used for irrigation in Kampala. Irrigation is mainly informal and water is obtained from wherever possible, although the case of JK Florists Ltd is well known to city authorities. Wastewater irrigation in Kampala supports livelihoods for various families. This is mainly done informally and there is need for intervention by the authorities to streamline the practice.

Using the WHO guidelines to make judgments over the safety of wastewater use, without taking the various 'types' of urban wastewater irrigation into consideration, drives policy makers and technocrats towards inappropriate conclusions.

It is an over-simplification to consider 'urban wastewater irrigation' as a single activity with uniform characteristics, open to a standard response from planners, policy makers, or technologists. Recognition of this variation is essential to effective discussion of wastewater irrigation practice, or to formulation of recommendations regarding its regulation.

Acknowledgments

I am grateful to the following: NEMA and the Ministry of Health for allowing me to participate in this survey; Kampala City Council for providing necessary information; and the Commissioner of the Uganda Meteorological

Department for allowing me time to participate. To my colleagues L. Tazalika, S. Tanywa, Deus Bamanya, Paul Isabirye and P.R. Wanambwa, I am very grateful for your support.

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Graywater Treatment and Reuse for Water and Food Security in Lebanon

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Abstract

Although Lebanon has relatively high mean annual rainfall than neighboring countries, there is large seasonal variation in precipitation with 80-90% of rainfall in November-March. During the summer months there is no rainfall, leading to severe water scarcity. A major reason for water scarcity and deterioration of water quality is the fragmentation and weakness of water authorities, leading to inefficient water management. Another reason is contamination of available water resources, from haphazard discharge of raw wastewater and open dumping of solid waste. To address these problems at a household and community level, the Middle East Center for the Transfer of Appropriate Technology (MECTAT) initiated the Graywater Treatment and Reuse project in 10 towns in Lebanon's Rashaya Caza region. The project aims to treat and reuse household graywater to provide irrigation water, and boost crop production in backyard gardens. The project results reveal that graywater from household activities has the potential for irrigating crops and offers many social and financial benefits to improve the inhabitants' livelihoods.

Key words: Graywater, irrigation, gender empowerment, wastewater treatment, water scarcity, anaerobic digestion

1 Introduction

Variability and uncertainty characterize water resources in many countries of the Middle East (Bino 2003). Lebanon has a high mean annual rainfall (Beirut has 893 mm) compared with neighboring countries, but there is large seasonal variation in precipitation with 80-90% of rainfall in November-March. During the summer months there is no rainfall, leading to severe water scarcity.

In Lebanon, rapid population growth and socioeconomic transformations in recent decades have created heavy stress on both the quality and quantity of water resources. In 2000, the annual water availability was 2255 m^3 per capita. The total annual precipitation on Lebanon's land surface is estimated at 9,700 million m^3; most of this is lost or becomes unusable due to evapotranspiration, surface runoff, and contamination. As a result, many communities do not have sufficient water to meet their basic needs and to grow additional food.

A major reason for water scarcity and deterioration of water quality is the fragmentation and weakness of water authorities, leading to inefficient water management. Another reason is contamination of available water resources, from haphazard discharge of raw wastewater and open dumping of solid waste.

To address problems like this at a household and community level, the Middle East Center for the Transfer of Appropriate Technology (MECTAT) initiated the Graywater Treatment and Reuse project in 10 towns in Lebanon's Rashaya district. The project is funded by IDRC, and aims to treat and reuse household graywater to provide irrigation water, and boost crop production in backyard gardens. For a background story on the human dimension of the project in one town, Tannoura, and the problems faced by families that the project is tackling, see Box 1.

1.2. Description of the graywater technology

The graywater treatment kit used in the project is four polyethylene (PE) barrels in a line and interconnected with PVC pipes (Figure 1). The first barrel is a grease, oil, and solids separator and thus acts as a pre-treatment or primary treatment chamber, where the solid matter from the influent graywater settles and components, such as grease and soap foam, float. This barrel has a cover to allow cleaning it of both floating and settled material.

Once solids and floating material are trapped in the first barrel, the relatively clear water from the first barrel enters the bottom of the second barrel. Next, the water from the top of the second barrel enters the bottom of the third, and similarly enters the fourth. In the two middle barrels, anaerobic bacteria decompose components of the organic material in the graywater through anaerobic digestion. The last barrel is a storage tank for treated graywater and when it is filled, a float device switches on a water pump which delivers the treated water through drip irrigation to water 20-30 trees for an average family of 6-8 members. Laboratory results indicate that irrigation with treated wastewater is safe and that it has no environmental and health impacts.

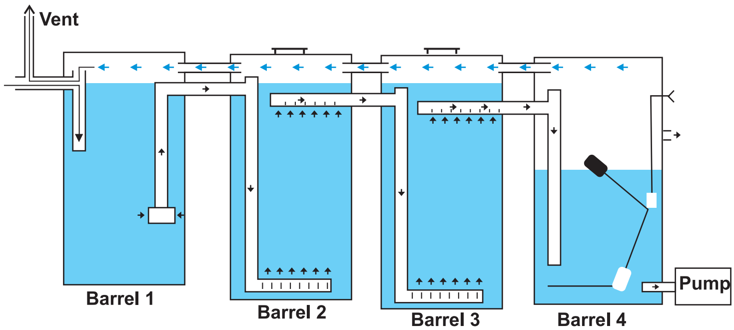

Fig. 1 The four-barrel graywater system.

1.3 Description of the confined trench system

Two plastic barrels and a dug trench filled with gravel constitute the confined trench (CT) unit. The first barrel is a grease, oil, and solids separator and thus acts as a pretreatment or primary treatment chamber as above for the graywater treatment kit. The first barrel has 160 L capacity and a large cover, which can be closed tightly and opened for clearing floating and settled material. A 3-m-long trench (1 m wide and 1 m deep) is dug close to the first barrel, and is filled with 2-3 cm size graded gravel.

Pretreated wastewater from the first barrel enters the bottom of the trench from one side and runs slowly to the other end. The trench is lined with PE sheet that is 400–500 μm thick. The sides of the trench are plastered with a mud layer so that sharp stones do not puncture the PE sheet. A plastic barrel of 120 L capacity is perforated and buried in the gravel at the exit end of the trench so that water runs throughout the trench and upwards to fill this barrel. When the barrel is filled, a float device switches on a small water pump, which delivers the water through the drip irrigation network. The residence time of graywater in the trench is 2-4 days under anaerobic conditions. The confined trench unit can serve more than one nearby family sharing same garden plot and can also deliver more water.

2 Material and methods

A number of physical, chemical, and biological parameters were tested: biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total phosphate (TP), total nitrates (TN) and fecal coliforms. These were regularly tested in six units, on a weekly basis over three months starting in June 2007. A total of 92 samples were taken and tested.

Box 1. The human dimension: rationale for graywater treatment in Tannoura, Lebanon

Children are running back and forth with empty water containers in their hands, while mothers are stacking containers filled with water in a wheelbarrow. A donkey is waiting at the side of the road for its owner to load it with water bins, while a water tanker is honking its horn to clear the way. The entire crowd is waiting for Zahia and her daughters to finish filling their last container from the Tannoura spring, "All this trouble with those containers for so little water that I can only use to clean floors. This water is so contaminated I can't even wash my family's clothes with it", says Zahia.

Tannoura suffers from water shortages and many water-related problems. The houses were never connected to the municipal water supply, their groundwater is too deep to be extracted economically, and their only spring (previously the only freshwater supply), is polluted by wastewater infiltration. Tannoura's spring water is so contaminated by sewage that it cannot be used for dishwashing or even washing clothes. It is only used for cleaning floors and irrigating a few ornamental plants that survive the long dry summers.

The residents of Tannoura have to buy water by truckload, at US$ 10 per 2000 L, which is expensive for families living on an average of US$ 450 per month, and needing an average of four loads per month. Those who cannot afford it are obliged to adopt water-saving behaviors to minimize buying water and make optimum use of their available water. Thus, most households reuse water 2–3 times before discharging it to the cesspit. Dishwashing and clothes washing water is collected for floor cleaning, and then recollected for flushing toilets. Sinks and showers are not common in Tannoura as they consume a lot of water and do not facilitate collection for further reuse.

Tannoura is equipped with a water pipeline network and two water reservoirs, which were first implemented 40 years ago and replaced 20 years later. However, people never received water at home, because their network was never connected to the Shamsine water network, which supplies potable water to the Rashaya district (*caza*). "Today these reservoirs and networks are corroded since they were never filled with water. The residents have lost faith in solving their problem and are now skeptical about any proposed project", said the Mokhtar of Tannoura, Mr. Moufid Abou Zor.

For over 20 years, the Municipality of Tannoura, with the cooperation of various influential people in the area, has tried to solve this water issue. However, no projects have been completely implemented and promises have not been fulfilled. Every four years, during the election season, projects are proposed and improvements are promised, people start hoping, but nothing has been achieved. "The last of these promises came from Speaker of the House of Parliament himself four years ago", complained Mr. Abou Zor, "We thought that it was going to be the end of our sufferings, but as usual they were all promises in the wind".

However, the year 2006 brought hope to the villagers when the Middle East Center for the Transfer of Appropriate Technology (MECTAT) initiated the Graywater Treatment and Reuse project in Tannoura, funded by the International Development Research Centre (IDRC) of Canada. The project aims at reusing treated graywater, (wastewater from kitchen sinks, washing machines, and showers) as an available resource that has not been utilized so far and with potential to provide irrigation water, and boost crop production in backyard gardens.

The project benefits 36 houses in Tannoura. Each house was equipped with three or four-barrel treatment kit, in which collected graywater is anaerobically treated for 1-2 days, and then automatically pumped into a drip irrigation network in the garden. "Thanks to the graywater project, I can finally make use of my arid backyard, and grow vegetables and fruits for my children by using the graywater that we generate, at no cost and without any effort", said Amal Serhal, a resident of Tannoura.

The project is not only scientific research, but also has a participatory social and educational component, to improve the residents' quality of life. Women are empowered through several training and decision-making activities. "Thanks to the training on food processing I will be able to save money by preparing my own food", said Ikhlas Abu Zor. As for Itab, the 18-year-old member of a local committee for graywater beneficiaries, she hopes that her participation in the committee will encourage other women to participate in improving their village's environment.

The success of the graywater project, in Tannoura and nine other towns in Rashaya Caza in which the project is being implemented, would encourage the government to adopt smaller graywater projects, simple to implement and with results felt at household and community levels. Tannoura is not an exception in the Middle East, where thousands of towns suffer from the same problems. Environmental conditions worsened by political negligence are making water shortage one of the main issues of the 21st century.

Table 1 Comparison of different physical, chemical, and biological parameters of four-barrel and confined trench (CT) graywater systems

Four-barrel system												
	BOD mg L^{-1}		**COD mg L^{-1}**		**Fecal Coli CFU mL^{-1}**		**TSS mg L^{-1}**		**Total P mg L^{-1}**		**Total N mg L^{-1}**	
	1st Barrel	**4th Barrel**	**1st Barrel**	**4th Barrel**	**1st Barrel**	**4th Barrel**	**1st Barrel**	**4th Barrel**	**1st Barrel**	**4th Barrel**	**1st Barrel**	**4th Barrel**
Unit 1	909.9	705.7	3270.7	1089.3	637.1	1322.6	332.1	251.5	101.3	67.9	58.6	38.4
Unit 2	1182.5	961.5	1349.3	925.1	450.1	380.0	123.3	73.8	27.9	27.7	61.4	44.3
Unit 3	1556.2	1379.0	2768.5	2220.8	43.3	32.5	7635.6	161.0	4.1	4.3	26.0	24.4
Unit 4	4169.8	3012.9	6660.7	4892.9	4.8	25.2	1619.5	555.0	9.2	15.4	67.1	62.7
Unit 5	1329.1	66.2	2453.1	681.3	754.3	72.9	236.0	119.9	53.7	17.5	84.0	37.9
Confined trench system												
	BOD mg L^{-1}		**COD mg L^{-1}**		**Fecal Coli CFU mL^{-1}**		**TSS mg L^{-1}**		**Total P mg L^{-1}**		**Total N mg L^{-1}**	
	1st Barrel	**2nd Barrel**	**1st Barrel**	**2nd Barrel**	**1st Barrel**	**2nd Barrel**	**1st Barrel**	**2nd Barrel**	**1st Barrel**	**2nd Barrel**	**1st Barrel**	**2nd Barrel**
CT unit	2020.8	238.8	3178.6	506.4	1190.0	752.7	345.1	95.9	36.0	8.0	71.9	36.1

The tests were conducted in high profile university laboratories. For the four-barrel system, samples were collected from the first and the last barrels; for CT the samples were from both barrels. Due to the large distance between the sampling sites and the laboratory (> 110 km) all samples were kept in darkness at 4°C. The laboratory results are summarized as average values of all parameters (Table 1).

3 Results and discussion

The average measurements in five houses where four-barrel systems were installed, and one restaurant where a CT was installed are given in Table 1. Some barrels did not show the expected parameter results, due to lack of maintenance and cleaning in addition to slow cycling of water in the barrels. There were efficient reductions of different parameters in those units with good checkup and maintenance (Unit 5 and CT). However, less cleaned units and those where the water cycle was slow also had acceptable chemical and biological pollution reduction. It should be noted that the residence time of graywater in the systems of Tannoura was 1–3 days, due to the very low water consumption rates. Thus, the effluent still had high BOD values.

Four-barrel system. BOD and COD were very high in the influent (Barrel 1) of all units. These high values can be caused by the way that villagers use water before reaching the first barrel. Due to the scarcity of water, it is used and reused before its final arrival in the treatment unit, and so loads the water with high COD and BOD. Elevated BOD and COD could also be caused by trucks providing poor quality water with high background values. It is important to note that high BOD and COD values characterize agro-alimentary water discharges.

Fecal coliforms were reduced in four of the five units. In Unit 1, the increase in colony-forming units (CFU) was abnormal relative to the other units. This could be caused by a slow water cycle between the first and fourth barrels, which provides time for bacteria to multiply in such a nutrient-rich environment. The efficiency of the settlement procedure in the system was shown in all five units, by the acceptable reductions of the TSS, TP, and TN parameters.

CT system. the CT system at a local restaurant in the project area was designed to receive large volumes of graywater. All studied parameters show that if well maintained, the system is very efficient in graywater treatment, even with large water quantities entering with high BOD and COD loads. A typical set of laboratory test results for the four-barrel treatment kit of a beneficiary (Zakiyeh Serhal), for 20 June 2007, is presented in Table 2.

Table 2 Comparison of different chemical, and biological parameters based on a typical set of laboratory test results for the four-barrel treatment kit of a beneficiary, Zakiyeh Serhal

Parameter	Barrel 1	Barrel 4
BOD (mg L^{-1})	898	21
COD (mg L^{-1})	1432	369
Fecal coliform (CFU/10 mL)	14	5
TSS (mg L^{-1})	349	153
Total P (mg L^{-1})	49	26
Total N (mg L^{-1})	72	24

4 Conclusions

MECTAT is the leader in introducing the graywater treatment systems in Lebanon, aiming to mitigate the countless problems of water scarcity and wastewater treatment in an arid and deprived region. Rashaya Caza was the first Lebanese region to implement a large-scale graywater treatment system for backyard irrigation. Expansion of the project in southern Lebanon is planned for the near future. Our results and field experience showed that graywater from houses is technically efficient for irrigating crops and offers many social and financial benefits.

Acknowledgments

This research project would not have been possible without the valuable contribution of the IDRC of Canada/Regional Water Demand Initiative (IDRC/WaDImena).

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Effects of Sewage Sludge on Heavy Metal Accumulation in Soil and Plants, and on Crop Productivity in Aleppo Governorate

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Abstract

Although sewage sludge is a good source of nutrients for plant growth, the presence of heavy metals in sludge can limit its use. We conducted a field study to evaluate the effects of soil application of sludge on heavy metal accumulation in soil and plants and on the productivity of wheat, maize and vetch. There were four treatments: (i) control; (ii) application of inorganic fertilizer according to the recommendation of the Ministry of Agriculture and Agrarian Reforms (MAAR); (iii) application of sludge equivalent to the MAAR-recommended nitrogen application; (iv) application of sludge at double the rate used in (iii). The experiment was conducted at the Kamari Research Station in Aleppo. Analysis of soil before sludge application and after harvest reveals significant build up of some heavy metals. Similarly in crops, heavy metal content increased with the increased application rate of sludge. In terms of other parameters, there was significant increase in organic matter and plant-available soil P levels in sludge-fertilized treatment. There were no significant differences for wheat yield between the sludge-fertilized treatments (2.66 and 2.86 t ha^{-1}) and mineral-fertilized treatment (2.93 t ha^{-1}). Maize yield increased significantly in sludge-fertilized treatments compared to the control (3.88 t ha^{-1}); the highest yield (6.34 t ha^{-1}) was in the treatment fertilized with double the amount of sludge. Vetch production also followed a similar pattern. Based on the results of this study, it is concluded that sludge application to the soil is effective in improving crop yield. It is unlikely that a single factor in sludge was responsible for the yield improvement rather a combination of macro and micronutrients and organic matter supplied by the sludge. The addition of heavy metals to the soil with the application of sludge was minimal.

Keywords: sewage sludge, organic matter, heavy metals, wheat, maize, vetch, Syria

1 Introduction

Sewage sludge is a good source of micro and macronutrients and organic matter (OM) for plants. However, unquantified and unscientific application of sewage sludge can be detrimental to plant growth, animal nutrition, and human health. Crop responses to sludge application vary by source, application rate, plant species, soil type, weather conditions, and management practices (Rabie *et al.* 1996). Application of sewage sludge can improve soil structure and increase infiltration rate, aggregate stability, and soil water holding capacity (Sort and Alcaniz 1999). However, heavy metals in sludge can limit its use (Barriquelo *et al.* 2003), potentially adding high concentrations of Cd, Cu, Ni, Pb, and Zn to soil can cause serious problems to plants and their consumers. The Syrian government is establishing sewage treatment plants in towns and districts, and the annual amount of solid organic waste from these plants is expected to reach 0.2 million t in 2010. There have been few studies carried out in Syria that address the implications of sludge application. Based on a field study, we evaluated the effects of sludge application to soil on heavy metal accumulation in soil and plants and on the productivity of wheat, maize and vetch.

2 Materials and methods

2.1 Soil description

The top 30 cm layer of red soil (Inceptisols) was collected from Kamari Research Station, Aleppo, Syria, and analyzed for the following: organic matter, available P according to Olsen *et al.* (1954); total N using the Kjeldahl method; organic matter by wet oxidation; available K by extracting with 1 mol L^{-1} ammonium acetate (1:5 ratio) and using a flame photometer. Soil organic matter content was 1.23%, total nitrogen level was 0.06%, available concentrations of P and K were 7.5 and 469 mg kg^{-1}. With 23.3% $CaCO_3$, the soil was calcareous in nature. pH was in the alkaline range, and EC1:5 was 0.4. Soil texture was 26% sand, 18% silt, and 56% clay.

2.2 Sludge characteristics

The sludge used in the experiment was sampled and analyzed for physical and chemical properties. The samples were digested using the wet method (Walinga *et al.* 1995) and total N and P were estimated using a Skalar auto analyzer. Total K was estimated by flame photometer.

Inorganic N was extracted using KCl (1:10) and measured using an auto analyzer. Sludge was digested by $HClO_4$ for micronutrient determinations and digested with aqua regia to determine heavy metal concentrations by atomic absorption spectrophotometer. Bulk density of the sludge was 0.86 g cm^{-3}. With pH value of 6.37, the sludge was in acidic in reaction. The salinity level expressed in terms of EC was 3.38 dS m^{-1}. Other characteristics of sludge are given in Tables 1 and 2.

Table 1 Physical and chemical characteristics of sewage sludge used in the study (average of three samples)

Sludge source	Moisture (%)	OM (%)	Total N (%)	K_2O (%)	P (mg kg^{-1})
Aleppo wastewater plant	6.5	40.5	3.70	1.35	132

Table 2 Total concentration of metal ions (mg kg^{-1}) in sewage sludge used in the study (average of 3 samples)

Sludge source	Cd	Ni	Pb	B	Cu	Fe	Mn	Mo	Zn
Aleppo wastewater plant	2.30	78.4	71.6	117	230	2400	159	30	1025
Allowable limits	20	200	800	-	1000	-	-	30	3000

2.3 Experimental design and treatments

A completely randomized complete block design with four replications was used; plot size was 5 ×10 = 50 m^2. There were four treatments: (i) control; (ii) application of inorganic fertilizer according to the recommendation of the Ministry of Agriculture and Agrarian Reforms (MAAR); (iii) application of sludge equivalent to the nitrogen application as recommended by the MAAR; (iv) application of sludge at the rate double that used in treatment 3.

2.4 Cultivation and fertilization

Wheat, maize, and vetch were cultivated for three seasons during 2004-2006 in crop rotation. Nitrogen and P were added as per MAAR recommendations. Sludge was added to soil after calculating the required amount.

3 Results and discussion

3.1 Effect of sludge on nutrient availability status in soil

There were no significant differences in OM content of soil under wheat and maize (Table 3) due to good initial OM content in soil (Table 1). After the third crop in rotation (i.e. vetch), the addition of sludge significantly enriched soil OM especially in T4 where OM increased significantly over control (T1).

Table 3 Total N, available P, and organic matter (OM) in 0-30 cm soil depth after harvesting wheat, maize, and vetch crops.

Treat-ment	Wheat			Maize			Vetch		
	OM	Total N	Available P	OM	Total N	Available P	OM	Total N	Available P
	%		mg kg^{-1}	%		mg kg^{-1}	%		mg kg^{-1}
T1	2.1	0.084 b	4.1 c	2.13	0.106	3.96 b	1.65 c	0.018 b	3.48 b
T2	1.9	0.110 a	7.7 a	1.97	0.100	6.89 b	2.23 b	0.03 ab	7.68 a
T3	2.2	0.092 ab	6.3 ab	2.06	0.103	8.33 b	2.49 ab	0.06 a	6.15 a
T4	2.2	0.103 ab	5.2 bc	2.13	0.107	19.10 a	2.90 a	0.04 a	5.73 ab
LSD	-	0.023	2.0	-	-	8.03	0.45	0.02	2.28

Sludge addition increased total N in soil; in case of wheat rotation, the total N increased by 23% compared with control (Table 3) because of high N in sludge (Table 1). Available P in soil was significantly different between treatments. Previous studies reveal that sludge addition can noticeably increase total N and available P levels in soils (Hernandes *et al.* 1991, Oudeh 2002).

3.2 Effect of sewage sludge on heavy metal accumulation in soil

There was no significant effect of sludge application on heavy metal (Cd, Ni, Pb, and Cr) concentrations in soil after wheat harvest, the first crop in rotation. Cadmium levels were found to higher in post-harvest maize plots where sludge was applied twice. The concentrations of other metal ions also increased after the harvest of vetch, the final crop in rotation (Table 4). In general, heavy metal accumulation was below allowable levels of Cd (0.01-2 mg kg^{-1}), Ni (5-500 mg kg^{-1}), Pb (2-200 mg kg^{-1}), and Cr (10-150 mg kg^{-1}) (Adriano 1986).

Table 4 Cadmium (Cd), nickel (Ni), lead (Pb), and chromium (Cr) levels in soil (mg kg^{-1}) after harvest of wheat, maize, and vetch crops

Treat-ment	Wheat				Maize				Vetch			
	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr
T1	0.125	101.7	8.6	104	0.70 b	124.9	7.9	95.7	0.41	59.2 b	3.72 b	58.3 b
T2	0.140	105.7	8.0	104	0.15 a	120.8	4.7	96.2	0.53	75.7 a	3.93 ab	84.7 a
T3	0.135	96.5	8.0	104	0.13 ab	124.2	8.3	93.2	0.60	68.5 ab	4.50 a	85.2 a
T4	0.130	103.5	7.0	103	0.18 a	124.8	10.4	97.0	0.77	65.0 ab	4.13 ab	75.5 a
LSD	-	-	-	-	0.07	-	-	-	-	13.2	0.66	13.7

3.3 Effect of sewage sludge on heavy metal accumulation in plants

There was no effect of sludge on metal ion concentrations in wheat and maize (grain and straw; Table 5). There was an increase of Cd and Cr concentrations in both grain and straw of vetch. These results are in agreement with those of Chu and Wong (1987). Heavy metal accumulation in all the crops was within allowable limits (Cd 0.05-1.2, Ni 0-4, Pb 0.1-30, and Cr 1-5, all mg kg^{-1}; Adriano, 1986).

Table 5 Cadmium (Cd), nickel (Ni), lead (Pb), and chromium (Cr) concentrations (mg kg^{-1}) in grain and straw of wheat, maize, and vetch

	Wheat				Maize				Vetch			
	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr
Grain												
T1	0.09	0.8	0.20	0.97	0.06	0.27	5.7	3.8	0.51 b	2.8	0.93	59.2 b
T2	0.09	0.8	0.20	0.95	0.09	0.31	6.3	4.0	0.55 b	2.3	1.07	75.7 a
T3	0.08	0.8	0.20	0.97	0.08	0.16	6.2	3.9	0.61 ab	1.8	1.08	68.5 ab
T4	0.09	0.8	0.20	1.04	0.11	0.15	4.5	3.8	0.79 a	1.7	1.09	65.0 ab
LSD	-	-	-	-	-	-	-	-	0.21	-	-	13.2
Straw												
T1	0.18	1.8	0.95	2.10	0.20	0.21	11.1	4.7	0.05 b	3.1	0.29 ab	0.8
T2	0.19	1.2	0.97	2.30	0.21	0.25	11.5	4.7	0.09 ab	3.3	0.23 b	1.1
T3	0.18	1.2	0.98	2.20	0.18	0.18	10.6	3.6	0.12 a	6.6	0.47 a	0.2
T4	0.19	1.3	0.98	2.40	0.21	0.17	12.2	3.8	0.09 ab	6.2	0.40 ab	0.5
LSD	-	-	-	-	-	-	-	-	0.05	-	0.24	-

3.4 Crop yield

There was a significant increase in wheat grain yield from the sludge-fertilized treatments compared with control (Table 6). T4 was the best with significant differences to controls and the chemically fertilized treatment. Similarly for maize grain production, sludge addition was significantly better than control; with T4 the best, significantly more than control and the chemically fertilized treatment. For vetch grain production, sludge addition was significantly better than control. Again, T4 was the best, significantly more than control and the chemically fertilized treatment. Other studies have shown high yields after sludge application, because of its contribution to greater availability of macro and micronutrients in the soil (Barriquelo *et al.* 2003).

Table 6 Grain yield (t ha^{-1}) of wheat, maize, and vetch as affected by the application of chemical fertilizers and sewage sludge application

Treatment	Wheat	Maize	Vetch
T1	2.03 d	1.100 c	9.8 b
T2	2.83 c	1.775 b	9.89 b
T3	3.3 0 b	2.150 b	11.41 b
T4	3.85 a	3.050 a	12.97 a
LSD	0.20	0.450	1.88

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Marginal-Quality Water in Agriculture: Impact on the Environment and Opportunities for Improving its Use in the Jabbul Area of Syria

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Abstract

This paper examines a study on the use of marginal-quality water in the Jabbul area in Syria. The study aimed at assessing the sources and qualities of water used for irrigation and investigating the perceptions of different stakeholders regarding the use of marginal-quality water for agriculture and its disposal into a wetland downstream. These insights, together with results of water quality sampling led to suggestions for improvements in using marginal-quality water in the area. The research was accomplished through interviews and water sampling. Generally, marginal-quality water was suitable for irrigation, and total nitrogen levels were sufficiently high that farmers could potentially benefit from the nutrients. There is need for a holistic approach in awareness of quality, use, and potential effects of marginal-quality water by involving all stakeholders.

Key words: Marginal-quality water, irrigation, nutrient benefits, drainage water, wastewater, Syria

1 Introduction

The Jabbul Basin is a closed basin with a total area of 5,075 km^2 in the Aleppo Province, one of 14 Syrian provinces. This basin contains the Sabkhat-Al-Jabbul, a large flat saline depression of about 270 km^2 (Serra *et al.* 2006) and to its north, northwest and west are irrigated areas that were the center of this research. Due to low annual precipitation (200-350 mm), most farmers supplement crop water requirements with irrigation water draining from irrigated fields or mixed water (a mixture of raw sewage and irrigation drainage water). This practice is in line with the global trend in most water scarce regions where wastewater is used in irrigated agriculture because of increasing pressure on freshwater resources and the potential water crisis from projections of water scarcity.

In most developing countries, unplanned wastewater irrigation is quite common and important for farmers' livelihoods (IWMI 2003). However, there is a need to optimize the use of wastewater, to maximize benefits and minimize its negative health and environmental impacts, especially in unplanned systems. The Jabbul area falls in this scenario, with unplanned irrigation using drainage water and mixed water, whilst unabstracted marginal-quality water is discharged into a 'Wetland of International Importance' under the Ramsar Convention (Ramsar 2006). Unplanned wastewater irrigation can be a health hazard through farmers coming in direct contact with wastewater or through crop contamination (Boom and Voorthuizen 1999). Benhoummane *et al.* (2001) reported that crops irrigated with wastewater had significant increases in stem length, dry weight, and number of branches per plant because of the high supply of nitrogen (N) compared with crops without wastewater Irrigation, demonstrating the importance of wastewater in supplying nutrients. Better use of marginal-quality water could be made through multi-quality irrigation practices, either through blending or alternating irrigation with waters of different qualities (Abbott and Hasnip 1997, Lazarova *et al.* 2005). This paper examines a study on the use of marginal-quality water in the Jabbul area in Syria.

2 Material and Methods

2.1 Area description

The study was conducted in the Jabbul Basin of Syria. To the north, northeast and northwest of the wetland is an irrigation canal network where the irrigated areas are equipped with a surface and sub-surface drainage system that conveys irrigation drainage water towards the wetland The towns of Sfireh and Tal Aran discharge raw sewage into the main drainage channel thus forming a mixture of raw sewage and irrigation drainage water.

Rainfall in the area occurs in winter during October/November-April/May. Temperatures are 2-10°C in January and 21-37°C in July (Serra *et al.* 2006). Agriculture is by far the most significant activity in the Jabbul area. In summer, crops are cultivated using irrigation; the main crops are cotton and maize and minor crops are sunflower, sugar beet, and a range of vegetables. In winter, the main crop is wheat, with minor crops like faba-bean and barley. Irrigation is used to supplement winter rains. Sheep rearing is also an important agricultural activity.

2.2 Methods and techniques

The research was carried out in three distinct parts as described below.

Rapid assessment of sources and quality of water in the Jabbul area
The area was rapidly assessed concerning the generation and use of marginal-quality water, to delineate it into a manageable unit for detailed interviews. A total of 26 rapid interviews were conducted in four main areas around the towns of Sfireh, Dayr Hafir, and Al Bab, and also around the village of Jabbul. In situ measurements of pH, electrical conductivity (EC), and temperature of water sources were recorded.

Establishing the extent of marginal-quality water use and stakeholders' perceptions
About 43 semi-structured and detailed farmer interviews were conducted; split into 22 with respondents who used mixed water, and 21 that used drainage water as the marginal-quality water source. Five group interviews were conducted in the same villages and five institutional stakeholders were interviewed, i.e. officials from the Town of Sfireh, the Health Department, and the Ministries of Irrigation, Agriculture, and Environment. Ranking and matrix scoring were often used in conjunction with interviews to establish the ranks and preferences of respondents where several alternatives existed. After each farmer interview, field measurements (of water pH, EC, and temperature) were conducted, GPS coordinates recorded and observations noted.

Assessment of quality of marginal-quality water in the Jabbul area
Fourteen water samples were collected in duplicate from sampling sites inclusive of the wetland and drainage channels conveying both drainage water and mixed water towards the wetland.

3 Results and discussion

3.1 Health aspects of marginal-quality water

About 59% of the respondents who used mixed water complained of skin rashes that they attributed to raw sewage mixed with drainage water before abstraction, compared with only 5% of respondents using drainage water who complained of skin rashes. About 36% and 95% of the respondents irrigating with mixed water and drainage water, respectively, did not associate marginal-quality water with health problems. Discussing health issues with farmers in connection with marginal-quality water was a sensitive issue.

3.2 Group discussions

Group discussions revealed that marginal-quality water is widely used in the area; about 80% of farmers were irrigating with marginal-quality water among other sources. An average of 45% of the irrigation water requirements in these villages were met by marginal-quality water. There were mixed responses concerning nutritional status of marginal-quality water and fertilizer adjustments when using this water, mainly due to pollution. Marginal-quality water was viewed as a health hazard by three groups because of skin irritations perceived due to irrigation with untreated wastewater. The proposed ways in which marginal-quality water management can be improved in the Jabbul area include growing salt-tolerant trees, wastewater treatment before use or disposal, and use of protective measures during irrigation.

Using the above criteria (Table 1), it was concluded that the marginal-quality water sources of the Jabbul area were suitable for irrigation, except for one drain, 13-GD that had extremely high SAR, EC, and TDS values.

Table 1 Evaluation of the suitability of marginal-quality water for irrigation

Criterion	**Comment**	
	Mixed water	**Drainage water**
pH	Summer pH often exceeded threshold of 8.0	Most stations within acceptable range of 6.5-8.0
TDS	Ranged from no restriction to moderate restriction	All channels are suitable for irrigation use except channel 13-GD with levels far in excess of limit for severe restriction
Nitrates	Levels were within acceptable limits for both Syrian and WHO guidelines	Stations 12-GD and 13-GD on a few occasions exceeded the Syrian and WHO guidelines
SAR	Channels did not have risk for sodium toxicity	Channel 13-GD had an average SAR of 16.45 implying severe restriction because of the potential for sodium toxicity
EC	Most stations were within the slight to moderate restriction	Most channels were within the slight to moderate restriction except 13-GD which was in the severe restriction range

3.3 Opportunities for improving the use of marginal-quality water in the Jabbul area

Nutrient dynamics
The extent to which nutrients are used (as fertilizers) and generated (as by-products of marginal-quality water) was analyzed. Averages of farmers' estimates of their fertilizer applications were above the recommended

application rates, except for summer N fertilizer applications. Only 30% of farmers using drainage water adjusted fertilizers by up to 20% less than the recommended rates, whilst 40% of respondents who used mixed water adjusted the application rates by up to 30% less than the recommended rates.

The potential role of marginal-quality water in augmenting nutrient supply was evaluated for cotton and wheat (irrigation water application of 16,000 and 5,000 m^3/ha, respectively; Martin 1999). Four scenarios were considered, depending on the use of marginal-quality water, i.e. 100, 75, 50, and 25% of the irrigation water requirements being met by marginal water. Nutrient losses were pegged at 50% and considering that about 50% of the irrigation by marginal-quality water, the 50% scenario was adopted. The average total N concentrations, 33 and 24 mg L^{-1} for mixed and drainage water, respectively, used were based on laboratory analyses. Cotton farmers benefited by 95-130 kg N ha^{-1}, whilst wheat farmers realized 30-40 kg N ha^{-1} (Table 2).

Table 2 Potential N benefits (kg ha^{-1}) under different levels (25-100%) of marginal-quality water use

	Proportion of marginal quality water (%)			
	100	**75**	**50**	**25**
Cotton with mixed water	265	198	130	65
Cotton with drainage water	190	145	95	48
Wheat with mixed water	83	60	40	20
Wheat with drainage water	60	45	30	15

Nutrients and the Sabkhat Al-Jabbul

The drainage and mixed water (not abstracted) all drain into the wetland, carrying nutrients and other chemicals. Since 1998, when diversion of drainage water to the wetland started, loading may have occurred. Without mitigation steps, and coupled with the heavy fertilization by farmers, the associated algal blooms could encroach on the Ramsar site, though currently the problem is only evident in the drainage channel system. Adjusting fertilizer rates while irrigating with marginal-quality water may reduce loading.

Treatment options

Based on wastewater analysis from the town of Sfireh into the main drain, it is clear that the wastewater is rich in nutrients that could enrich water bodies downstream. The average levels of total N were 75 and 79 mg L^{-1} for the two discharge points. There were higher levels of phosphorous in wastewater (about 5.5 mg L^{-1}) than other water sources (< 1 mg L^{-1}). Wastewater treatment is one option for nutrient removal.

Human exposure control

Only 16% of farmers were observed to use protective measures (gum boots) in the field, yet many more respondents complained of skin rashes, showing significant potential for enhancing farmers' protection. Despite the effectiveness of protective clothing in avoiding contact with the water, it remains a poorly adopted practice.

Multi-quality irrigation practices

Though farmers are already passively practicing multi-quality irrigation practices in the Jabbul area, they could get greater advantage by blending. Alternatively, they could practice conjunctive water use of freshwater and saline water at different stages of crop growth (Sharma and Minhas 2005). It is difficult to implement mixing in the Jabbul area because of the lack of necessary mixing infrastructure, whilst it is more feasible to practice the latter option.

4 Conclusions

Marginal-quality water is widely generated in the Jabbul area. Drainage water is the bulk and the rest is domestic wastewater, representing an important water source for farmers. There were mixed reactions concerning quality of marginal water; a significant proportion rated the water of low quality due to high pollution levels. The wetland, once economically important in salt production, has lost a great deal of importance because of increasing and uncontrolled pollution levels. Wastewater is a potential health hazard; however, of all the sources of marginal-quality water, only one channel was unsuitable for irrigation because of exceeding WHO and Syrian thresholds. The potential nutrient gain from marginal-quality water is treated as a secondary benefit by most farmers due to low appreciation of fertilizer adjustment. The implementation of some optimization measures like multi-quality irrigation water use, use of protective clothing and wastewater treatment is not well considered, though these measures offer potential improvements in use of marginal-quality water. There is a lack of holistic approach to produce management options for reuse and disposal of marginal-quality water in the Jabbul area, and this requires input of all stakeholders in decision-making.

Acknowledgments

My special thanks go to the staff at ICARDA for coordinating the fieldwork and for excellent ideas, especially Drs Bruggeman, Qadir, and Turkelboom, as well as the Ministry of Irrigation in Aleppo, Syria for sharing data. My thanks also go to Dr Huibers at Wageningen University for guidance.

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Organic Compounds in Reclaimed Water: Soil, Plant, and Groundwater Contamination Caused by Irrigation

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Abstract

Secondary treated effluents carry a wide variety of organic pollutants of natural and anthropogenic origin. Some contaminants such as alkylphenols, detected in concentrations of nanograms to micrograms per liter, may act as endocrine disruptors. In arid and semi-arid countries where effluents are reused for irrigation, such contaminants in reclaimed water and irrigated soils are usually overlooked and there is likely to be soil accumulation of hydrophobic chemicals at various depths and aquifer contamination. Until now, plant contamination by organics remains of little concern for most toxic compounds. This short review aims at raising issues linked to long-term impacts of irrigation with reclaimed water on the agricultural environment (soil and groundwater) and outlines some results of ongoing research in Tunisia.

Key words: Reclaimed water, organic contaminant, irrigation, groundwater, soil

1 Introduction

Chemicals used in households, industries, and agriculture have been associated with wastewater with potential effects on ecosystem (Mills and Chichester 2005, Vethaak *et al.* 2005). Determining the nature, origin, and concentrations of organic pollutants in sewage water has increased in recent decades (Paxéus, 1995, Knepper *et al.* 2001, Gomez *et al.* 2007). The application of wastewater, raw or insufficiently treated (Kamizoulis *et al.* 2003), such as in some Mediterranean countries, is of concern because of risk of soil contamination by persistent organic pollutants or their metabolites, and infiltration to shallow and unconfined aquifers (MED-EUWI 2007).

This paper aims at raising issues linked to long-term impacts of irrigation with reclaimed water on the agricultural environment based on some results of ongoing research in Tunisia.

2 Organic contaminants in effluent

In secondary biological effluent, natural and anthropogenic organic compounds are variably degraded according to their physical-chemical characteristics, including solubility, and octanol-water (Kow) and organic carbon (soil)-water (Koc) partition coefficients. Qualitative and quantitative data on such released chemicals have and are being addressed. For instance, in Sweden, 137 compounds (mainly aromatic hydrocarbons, plasticizers, flame-retardants, and cleaning agents) were identified in three treatment plants at concentrations of 0.5-50 µg L^{-1} (Paxéus 1995). In graywater, Eriksson *et al.* (2003) identified 900 potential xenobiotics (detergents, perfumes, and coating agents) of which 66 were priority pollutants that included 34 surfactants. In Minnesota, more than 27 compounds were detected per sample in effluent from eight sewage treatment plants. Among 74 compounds commonly used, 44 were of domestic, industrial, or agricultural origin and nine were pharmaceuticals.

3 Organic contaminants in effluent-irrigated soils

Reuse of effluent for irrigation is a potential transfer pathway of organic contaminants to soil. In soil, the impacts of such practice on mobility and transformation of these compounds are not yet well addressed. Results from laboratory and field studies are sometimes contradictory because of variability of soil characteristics and/or effluent quality and biotic and abiotic mechanisms involved.

Since they are found even in controls, polycyclic aromatic hydrocarbons (PAHs) are among the most detected organics in effluent-irrigated soils (Song *et al.* 2006). Close proximity to industrial areas and roads may result in quite high concentrations (Chen *et al.* 2005). For alkylphenols, there are few studies on effluent contribution to soil contamination; and their soil biodegradation is not well understood (Shibata *et al.* 2006). In field conditions, very few experiments have focused on transport in soil columns and transfer to aquifers (Jacobsen *et al.* 2004). Some pharmaceuticals and personal care products are likely to persist in sewage-irrigated soils and be transported through them (Kinney *et al.* 2006) or attenuated by soil-aquifer treatment (Ternes *et al.* 2007). Thus, it is difficult to define substances that could be considered as pollutants and their respective concentrations (WHO 2006).

4 Contamination of groundwater by organic chemicals

The US Office of Technology Assessment considers water reuse in irrigation as a source of groundwater contamination with organic chemicals. Hence, there have been numbers of batch and lysimeter studies on the transfer of organic contaminants. In 1988, the US-EPA set standard methodology to study anaerobic biodegradation in groundwater of chlorinated compounds, PAHs, and phenols, to provide data for modeling (Aronson and Howard 1997). Minor degradation of surfactants (Ying *et al.* 2003) and pharmaceuticals (Lorphensri *et al.* 2007) in groundwater contributes to potential contamination of drinking water. As a whole, the impact of effluent irrigation on groundwater is considered insignificant, since a majority of organic pollutants are supposedly retained in soil (WHO 2006).

5 Organic pollutants in plants

Vegetation uptake of organic pollutants is governed by chemical and physical properties of the latter (mainly Kow), environmental conditions, and plant species (Simonich and Hites 1995). Molecular size, soil degradation, and plant metabolism seem to prevent contamination of edible parts (Committee on the use of treated municipal wastewater effluents and sludge in the production of crops for human consumption, 1996). However, some compounds have been detected in alfalfa leaves (Shore *et al.* 1995) and on the crop surface after irrigation. Uptake of xenobiotics from soil and water is based on partition models (Chiou *et al.* 2007); over and under estimation of contamination seems to be a matter of the parameters considered (Denys 2002).

6 Ongoing research in Tunisia: main results of a case study

In Tunisia, the interest in organic contaminants in effluent and effluent-irrigated soils is very recent. An area irrigated since the 1980s is being studied to provide qualitative and quantitative data on organic contaminants in reclaimed water and their transfer to irrigated soils. The integrated approach including bioassays (estrogenic and dioxin-like receptors cell lines) and instrumental analysis (gas chromatography-mass spectrometry) applied to water and soil samples from the Oued Souhil irrigated area has led to the following preliminary conclusions:

1. Alkylphenols were detected in irrigation water and exposed soils
2. Some organic contaminants in secondary effluents bind to estrogenic and dioxin-like receptors
3. Effluent irrigation and aquifer recharge allow transfer of organic contaminants to soils

4 Suspended solids may contribute to the transfer of hydrophobic compounds (Mahjoub *et al.* 2007)

Hence, a thorough characterization of organic contaminants in effluents and a study on leaching of more polar compounds in soil and on groundwater contamination by previous irrigation activity are desirable.

7 Conclusions

Some organic pollutants are released in secondary treated effluents. In freshwater-scarce countries (e.g. in the Mediterranean region), agricultural reuse of effluent may cause soil contamination. The more hydrophilic and non-degraded compounds are likely to be transferred to aquifers. In this field, more investigation is needed. In addition, plant uptake of organics should not be ignored.

Acknowledgments

Special thanks are addressed to Mr. Aounallah and the Agricultural Development Association of Oued Souhil for access to samples, and Unité 896, CRCM, INSERM Montpellier for bioassays.

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Research on Wastewater Re-use in Sudan: the Experience of the Environment and Natural Resources Research Institute

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Abstract

Despite the presence of the Nile river and other surface and ground water resources, Sudan, like other arid and semi arid countries, faces water shortage problems. Storage limitations, the erratic nature and distribution of rainfall, population growth, rising living standards, and accelerated urbanization, all threaten the water supply in general and agriculture in particular. This situation drives research to develop additional water resources as well as protect the existing ones. The Environment and Natural Resources Research Institute, a specialized research institute in Sudan, has been working for several years on reusing wastewater and sewage sludge in agriculture to solve both problems of environmental pollution and water scarcity in agriculture. There have been many research projects on the use of wastewater and sludge addressing cultivation of forest trees, ornamental plants, forage crops, fruits, and vegetables through monitoring of such water and sludge and of quantity and quality of agricultural products. The accumulation effects of both wastewater and sludge on the physical, chemical, and biological characteristics of soil have also been studied. This paper presents the wastewater and sludge reuse results and prospects.

Key words: sewage sludge, wastewaer treatment, heavy metals, wastewater irrigation, Sudan

1 Introduction

Sudan is the largest country in Africa and the Middle East, and covers an area of about 250 million ha in the tropical zone at 3-22° N and 22-38° E. One third of the total area is arable; however, only 21% of the arable land is cultivated. There are many surface and ground water resources in

Sudan. Rainfall provides much of the available surface water and varies significantly; the rainy season, especially in the north, is limited to 2-3 months and the rest of the year is virtually dry. Moreover, the rain is usually in isolated showers, which are highly variable in time and location. Furthermore, Sudan contains 60% of the Nile Basin and shares 22% of the Nile water with Egypt, according to the 1959 agreement. Owing to the population growth and water demand in different sectors, there is a need for long-term planning of research to improve water management in the country.

Scientific research in Sudan addressing water management is carried out by several universities and scientific research institute. The Environmental and Natural Resources Research Institute (ENRRI) is the one of the specialized research institutes of the National Center for Research in Sudan. ENRRI has worked for several years in many research projects concerning environment and natural resources, with wastewater reuse in agriculture as one of the main projects.

The research project reported here aims at sustainable use of treated wastewater while protecting the environment, providing economic benefits, and supporting the country's development, by conducting research on monitoring and reuse of treated wastewater and sludge in agriculture as a model for future use in Sudan.

2 Treated wastewater in Sudan

The first wastewater treatment plant in Sudan was established in the Elgoz area in south Khartoum in 1958, to treat about 13.5 million liters of sewage water per day from the central Khartoum area. This plant treated wastewater by the activated sludge process. In 1990, a new plant was established in the Soba area of south Khartoum with an oxidation pond system, to deal with increased volumes from the central Khartoum area and the industrial area. This plant was designed to treat about 40 million liters of mixed domestic and industrial water (Elrashid *et al.* 1998, 1999, Taha 2000)

3 ENRRI experience with treated wastewater

For several years, to evaluate reuse of wastewater and sludge in agriculture, ENRRI has implemented several wastewater monitoring and reuse experiments. These have aimed to demonstrate that treated wastewater reuse can be reliable, economically viable, socially acceptable, and environmentally safe (Diab *et al.* 2006, Osman *et al.* 2006).

4 Wastewater and sewage sludge characteristics

The physical, chemical, and biological quality parameters of treated wastewater and sewage sludge were conducted many times in parallel with reuse of these wastes in specific experiments (Tables 1 and 2). Most cases demonstrated the feasibility of reuse of wastewater and sewage sludge with some precautions.

5 Effect of wastewater and sewage sludge

During the years 1997-2007, many pot and field studies were conducted in the ENRRI nursery and in field locations in the Soba area. These studies evaluated the effects of various levels of treated wastewater and sewage sludge (fermented or non-fermented) on growth, yield, quality attributing characters, and the metal accumulation in tissues of different forestry species, forage crops, and vegetables.

Table 1 Characteristics of wastewater and sludge reported in 2002 from a wastewater treatment plant using oxidation pond system in Khartoum.

Parameter	Unit	Wastewater (mg L^{-1})	Sewage sludge
pH	-	-	7.35
OM	%	-	1.40
Na	mg kg^{-1}	5.0	44.00
K	mg kg^{-1}	4.7	32.15
Fe	mg kg^{-1}	0.1	5510
Cu	mg kg^{-1}	0.03	62.50
Cr	mg kg^{-1}	0.04	18.80
Pb	mg kg^{-1}	0.0	7.20
Cd	mg kg^{-1}	0.14	5.00

Table 2 Characteristics of wastewater and sludge reported in 2005 from a wastewater treatment plant using oxidation pond system in Khartoum

Parameter	Unit	Wastewater	Sewage sludge
pH	-	7.3	7.58
TSS	mg L^{-1}	1250	-
OM	%	-	29.29
Na	mg L^{-1}	7.5	187.5
K	mg L^{-1}	15.0	437.5
Zn	mg L^{-1}	00.0	537.5
Mn	mg L^{-1}	1.3	187.5
Fe	mg L^{-1}	72.5	10206
Cu	mg L^{-1}	9.0	225.0
Ni	mg L^{-1}	00.0	181.3
Cr	mg L^{-1}	15.3	575.0

Table 3 Maximum heavy metal concentrations (mg kg^{-1}) in lettuce (*Lactuca sativa L.*) and Jew's-mallow (*Corchorus olitorius L.*) as affected by treated wastewater

Metal	**Lettuce**	**Jew's mallow**
Fe	255.42	67.50
Cu	8.93	0.50
Ni	1.52	3.96
Cd	0.93	0.29
Pb	1.54	2.17

The studies indicated that increased application rates of treated wastewater and sewage sludge (fermented or non-fermented) significantly increased the yield, vegetative growth, and quality parameters for most tested plants. There was no significant effect on metal concentrations with wastewater and sludge levels; in most studies, the uptake of metals depended on plant species (Table 3). Metal residues were generally less than the maximum permissible levels for vegetables, with the exception of Cr in some cases; possibly due to low heavy metal concentrations in treated wastewater and sludge used. However, the high Cr concentration was due to the tannery industry that was dominant and regularly linked with the sewerage system.

6 Ongoing and future research

Several current studies are evaluating responses of various forest and tree species to different concentrations of treated wastewater. Other studies are evaluating the ability of some leguminous and oilseed crops to take up heavy metals from soil with elevated concentrations of such metals. A third category of research is studying the effect of wastewater on physical, chemical, and biological characteristics of soil. In the future, the effects of using gamma irradiation on treated sewage water as a safety measure, as well as mutation techniques to improve heavy metal uptake by plants, will be studied.

7 Conclusion

Preliminary research carried out at ENRRI indicates that treated wastewater could be a realistic new source of water for agriculture and also the best solution for disposal. However, intensive studies and research programs are needed to avoid negative effects of such water on soil, plants, and humans. It is very difficult to convey the benefits of wastewater reuse to people not directly involved with wastewater. Consequently, studies of public awareness and acceptance of wastewater reuse in agriculture should be conducted.

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Effect of Mixing Sludge with Surface Soil on Soil Physical Properties and Cotton Yield

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Abstract

We studied the effect of mixing sewage sludge with the surface soil on soil physical properties and cotton yield, using four treatments: (i) control; (ii) application of inorganic fertilizer according to the recommendation of the Ministry of Agriculture and Agrarian Reforms (MAAR); (iii) application of sludge equivalent to MAAR-recommended nitrogen application rate; (iv) application of sludge at double the rate used in (iii). The experiment was conducted in the 2004 season at the Kamari Research Station in Aleppo, Syria. Organic matter in the topsoil of the sludge treatments was significantly higher than in the control and mineral fertilizer treatments. Application of sewage sludge clearly improved the infiltration rate and soil-water holding capacity because of the high water holding capacity of the applied sewage sludge compared the soil. Cotton yield increased with increasing sewage sludge application, and the highest yield (5400 kg cotton/ha) was obtained from treatment received sludge double crop N needs.

Key words: sewage sludge, soil infiltration rate, water holding capacity, cotton, Syria

1 Introduction

Crop response to sewage sludge application differs from one sludge source to another, the rate of sludge application and the environmental conditions (Rabie *et al.* 1996). Several studies have shown a positive effect of sewage sludge application on crop yields (Chu and Wong 1987). However, there is a lack of comprehensive studies on agricultural use of sewage sludge in Syria.

We carried out a field study to evaluate the effects of sewage sludge application on cotton yield and soil physical properties. This study was initiated in May 2004 at Kittyan Research Station in Idleb Province and Kamari Station in Aleppo Province, Syria. It was a collaborative study between the Syrian Ministry of Agriculture and Agrarian Reform (MAAR) represented by the General Commission for Scientific Agricultural Research (GCSAR) and the Arab Center for Studies of Arid Zones and Dry Lands (ACSAD).

2 Materials and methods

To study the effect of mixing sewage sludge with topsoil on soil physical properties and cotton yield, we conducted two experiments with four treatments and four replicates using a randomized complete block design (RCBD). Soil and applied sewage sludge were analyzed before mixing with topsoil and cotton was grown after fallow. The RCBD treatments were as follows: T1, untreated soil (control); T2, soil receiving mineral fertilizers as recommended by MAAR; T3, soil receiving sludge as per cotton's needs in accordance with Syrian Standard No 2665 (2002); and T4, soil receiving double the amount of sludge used for T3.

Each plot was 10 m × 5 m and drip irrigation was used. Composite soil samples were taken from each depth. Soil texture was assessed by hydrometer. Soil bulk density was determined by taking samples using cylinders of known sizes. Total soil porosity was calculated from bulk density and real density for each depth (Table 1). Field capacity was determined in the field. Soil and sludge pH were determined on 1:5 extracts using pH meter. Electrical conductivity (EC) was assessed in saturated soil extract and irrigation water using an EC meter. Soluble ions in saturated extract were assessed as follows: K by flame photometer, available P by modified Olsen method, total and mineral N by Kjeldahl method, organic matter (OM) according to Jackson (1958). Cotton cv. Aleppo 90 was sown on 15 May 2004. The necessary cultivation practices were used and the number of bolls per plant and opening rates estimated. Yields and other characteristics of the cotton produced were recorded.

3 Results and discussion

The physical properties of Kamari soil and applied sludge are shown in Table 1. The sludge was characterized by low bulk density that decreased the bulk density of topsoil in Kamari and Kittyan, where the bulk density of the top soil in Kamari were 1.12, 1.09, 0.97, and 0.97 g cm^{-3}, and in Kittyan 1.14, 1.02, 0.96, and 0.97 g cm^{-3} for T1, T2, T3, and T4 treatments, respectively. Sludge application increased OM of topsoil. There was a significant increase in OM in topsoil of treatments that received sewage sludge compared with control and treatment that received mineral fertilizers.

Table 1 Physical properties of soil at Kamari Station prior to cultivation in 2004

Site	Depth (cm)	Particle-size analysis			Texture	Bulk density	Total porosity	$CaCO_3$	OM
		Clay	Silt	Sand		g cm^{-3}	%	%	%
Kamari	0-20	54	26	20	Clay	1.04	0.61	23.3	1.23
	21-40	56	25	19	Clay	1.13	0.57	24.7	0.91
	41-60	55	24	21	Clay	1.18	0.55	25.0	0.73
	61-80	56	22	22	Clay	1.12	0.58	25.9	0.35
Homs	Sludge*					0.81	0.69		39.7

* Sludge from Homs Plant. Moisture content was 56.7%

There were large variations between the curve of topsoil moisture properties from Kamari soil (T1) and the curve of sludge (Figure 1). The soil moisture characteristic curve on weight basis has the same trend but with smaller differences due to the low bulk density of the sludge. The application of sludge to the topsoil did not significantly affect soil moisture properties. The cumulative effect of sludge application did not appear at the time of application of 6 and 12 t ha^{-1} (equal to 0.25 and 0.50% of the weight of top soil, respectively) because the applied sludge was wet (about 40% moisture on weight basis) (data not shown). It is expected that the effect of sludge application on soil moisture properties would appear after sludge reaction with soil components and soil aggregation formation. There was no significant difference in moisture content of different layers for Kamari and Kittyan soils (data not shown) because of similar clay texture (Table 1), and that sludge amounts applied to Kamari soil were small. Infiltration rates in T4 soil were three times the rate in T1 (Figure 2), demonstrating the effect of sludge application. Where sludge application reduced the bulk density and hence improved top soil porosity.

Kamari soil was not affected by salinity as shown by the low EC of saturated extract (Table 2). The soil was relatively poor in available P and mineral and total N, but had a relatively high concentration of exchangeable K. Application of sewage sludge clearly improved water infiltration (Figure 2), especially at the beginning of the infiltration process when the top soil was dry.

Table 2 Chemical properties of soil at Kamari Station prior to cultivation in 2004

Depth (cm)	Available P mg kg^{-1}	Available K mg kg^{-1}	Mineral N mg kg^{-1}	Total N %	pH	EC dS m^{-1}
0-20	7.50	469	12.6	0.06	7.7	0.40
21-40	5.50	387	14.4	0.05	7.7	0.42
41-60	4.00	260	9.8	0.04	7.8	0.45
61-80	3.25	237	8.5	0.02	7.9	0.36
Sludge*	128	2400	235	2.46	6.5	1.80

* Sludge from Homs Plant. Moisture content was 56.7%

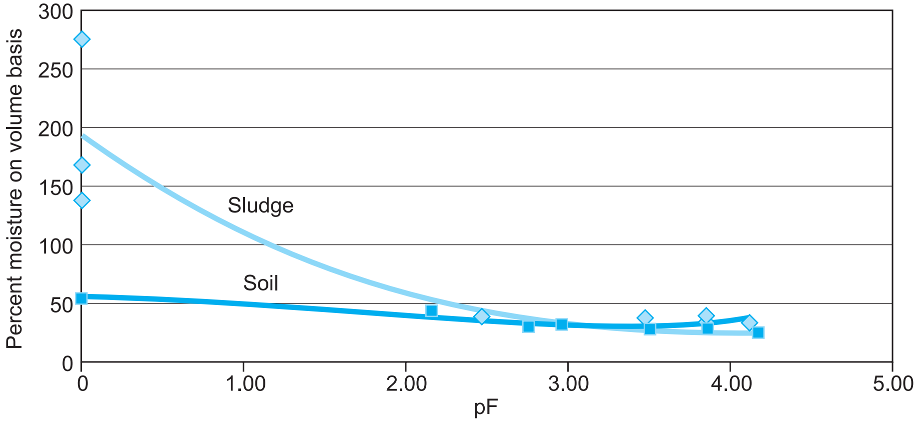

Fig. 1 Soil moisture characteristic curve of topsoil at Kamari Station and that of the sludge, on a volume basis

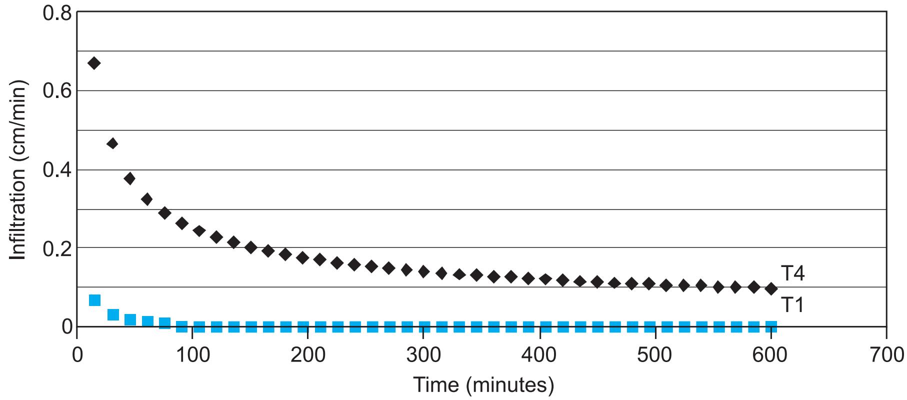

Fig. 2. Infiltration rate for soil of T1 and T4 treatments after two years of the experiment at Kamari Station in 2006

The double sludge treatment (T4) produced greater cotton yields than other treatments including the control at Kamari, while T3 was non-significantly superior at Kittyan. The average cotton yields were not significantly different ($P < 0.05$) between all treatments (Table 3).

Table 3 Average cotton yield, number of bolls and opening percentage for different treatments at Kamari and Kittyan Stations in 2004

Treatment	**Kamari**			**Kittyan**		
	Yield ($t\ ha^{-1}$)	**Bolls per plant**	**Opening (%)**	**Yield ($t\ ha^{-1}$)**	**Bolls per plant**	**Opening (%)**
T1 (control)	4.40	26	97	3.80	30	95
T2 (mineral fertilization)	4.85	35	96	4.74	31	94
T3 (sludge application)	4.90	36	97	4.87	34	97
T4 (double sludge amount)	5.30	34	97	3.73	30	97

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Fate of Pathogens in Tomato Plants and Soil Irrigated with Secondary Treated Wastewater

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Abstract

Pathogenic indicators, namely total coliforms, *E. coli,* and *Enterococcus* were measured on harvested tomato fruit and leaves and in soil irrigated with either freshwater, effluent of extended aeration wastewater treatment plant, or effluent of an integrated Upflow Anaerobic Sludge Blanket reactor and Rotating Biological Contactors pilot treatment-system. The plants were raised in a greenhouse during summer in Jordan. Drip irrigation was used in which laterals were covered with mulch to minimize contact between irrigation water and plants. Total coliforms and *Enterococcus* counts in all tomato fruit samples (except one) and *E. coli* counts in all fruit samples were < 1 MPN g^{-1} dry plant material. Although secondary treated wastewater had indicator pathogenic counts of 2-5 log units, there was considerable reduction in the collected soil samples 10 d after the last irrigation. All soil samples contained < 1 MPN g^{-1} dry soil of *E. coli,* while total coliform counts ranged <1-19.23 MPN g^{-1} dry soil. These results suggest that disinfection of reclaimed wastewater may not be necessary with respect to the measured indicator pathogens when proper agricultural practices are applied.

Key words: Wastewater reuse, tomato, soil, total coliforms, *E. coli*, *Enterococcus,* Jordan

1 Introduction

Wastewater reuse for agricultural production is common in several countries; however, there is a growing concern of possible environmental and health impacts. Emphasis is given to the control of microbiological contamination and many developing countries adopted the WHO (1989) guidelines of maximum allowable limits of indicator pathogens in effluent of treatment plants; in many cases, the guidelines were applied as national standards. However, production of 'standard effluent' is irrational when irrigation techniques and agricultural practices can also be used as barriers to pathogenic contaminants as suggested by the water chain approach (San'a Declaration, 2006). In this approach, irrigation technique is crucial for the selected wastewater treatment system. For example, sprinklers for irrigation of raw fresh crops require advanced systems for pathogen removal; however, suitable application of drip irrigation may require lower water quality. Thus, if proper irrigation techniques are used then the same quality of crops can be obtained with lower quality water.

The newly suggested WHO (2006) guidelines do not require pathogen removal only at wastewater treatment plants. Natural die-off, farming practices, applied irrigation systems, and produce washing are considered effective in reducing pathogens to safe levels. Risk management is particularly important even when treated effluent is disinfected. There is evidence that disinfection, especially using chlorine, is not effective in preventing regrowth of microorganisms downstream of treatment (Gantzer *et al.* 2001). In such cases, health risks associated with reclaimed water reuse are still present and agricultural practices are crucial in determining safe use of this water resource. There are few publications on the fate of pathogens in soil and plants when irrigating with either disinfected treated effluent or with treated wastewater not subjected to disinfection. The main objective of this research was to investigate the fate of pathogens on tomato plants and in soils irrigated with different qualities of wastewater under Jordanian conditions, provided that precautions were taken in regard to agricultural practices. This includes study use of drip irrigation covered with mulch to prevent direct contact between plants and treated wastewater.

2 Materials and methods

The experiment was performed in a 500 m^2 greenhouse built 60 m downstream of Abu-Nusier wastewater treatment plant located north of Amman. Half of the greenhouse was utilized for growing tomato with the following three water treatments:

1. Effluent of the existing activated-sludge treatment plant before chlorination
2. Effluent of a pilot anaerobic-aerobic system consisting of a combined Upflow Anaerobic Sludge Blanket (UASB) reactor followed by Rotating Biological Contactors (RBC)
3. Fresh water as a control

The pressurized irrigation system consisted of a pressure regulator at the inlet, a disc filter, sand filter, and a fertilizer injection unit at the storage tanks. A main line from each storage tank carried water to the greenhouse. Every plot in the greenhouse contained two laterals from a main line. Every lateral contained five drippers supplying 4.3 L h^{-1}. The field was ploughed twice before the experiment. The planting area was divided into blocks separated by paths 0.5 m wide. Water treatment plots were randomly distributed. The irrigated area was covered with mulch to prevent direct contact between irrigation water and plants.

Soil samples were collected both 5 and 10 d after the last irrigation. Samples were taken at four depths: 0-15, 15-30, 30-45, and 45-60 cm. Water samples were collected before each irrigation, while leaves and fruits of tomato plants were collected at the end of the experiment. Plant and soil samples were transferred directly to the laboratory for analysis. Wastewater samples were collected using sterile bottles containing sodium thiosulfate and the samples transferred directly to the laboratory for analysis. Total coliforms, *E. coli*, *Enterococcus,* and *Salmonella* were analyzed in all samples. A certain weight of sample (soil or macerated plant) was diluted to 100 mL using 0.85% NaCl as described by Poxton *et al*., (1989). Pathogens were then measured following the enzyme substrate test (APHA 1995). Wastewater sample determinations followed APHA (1995).

3 Results and discussion

The measured average total coliforms, *E. coli,* and *Enterococcus* in water used in treatments are shown in Table 1. No *Salmonella* was detected in any water samples. The values of biological indicators on tomato fruit, leaves, and in soils are shown in Tables 2 and 3, respectively. It is noteworthy that fruit in all cases (except one) had < 1 MPN g^{-1} dry plant of each biological indicator, although wastewater (Table 1) contained high pathogenic loads. According to WHO (1989), wastewater with qualities reported in Table 1 should not be used for unrestricted irrigation to prevent associated health risks. However, this study shows that when irrigation techniques and agricultural practices are taken into account, health risks are minimized at lower treatment costs. The present results were better than those of Manios *et al*. (2005) who concluded that there was pathogenic contamination on the surface of tomato and cucumber from indirect movement of pathogens by insects in the greenhouse. The mulch cover minimized contact between plants and wastewater. However, one measurement of total coliforms was 72 MPN g^{-1} dry plant and one measurement for Enterococcus was 21 MPN g^{-1} dry plant. According to WHO (2006) guidelines, washing produce would reduce pathogens by one log unit, which means that washing tomatoes would guarantee a safe product.

Table 1 Biological indicators measured for three water treatments

Parameter (MPN/100 mL)	10^5 x WWTP	UASB-RBC x10^5	Freshwater
Total coliforms	4.8	68.69	<1
E. coli	1.5	31.77	<1
Enterococcus	0.02	0.008	Not detected

Table 2 Biological indicators in tomato (leaves and fruit) for three water treatments

Parameter (MPN/g dry plant)		Freshwater	WWTP	UASB-RBC
Total coliforms	Leaves	<1	<1	<1
	Fruits	<1	<1(71.57)	<1
E. coli	Leaves	<1	<1	<1
	Fruits	<1	<1	<1
Enterococcus	Leaves	<1	<1(24.29)	<1(2.3x10^3)
	Fruits	<1	<1	<1(20.45)

* One sample had higher values, as given in prarentheses

Table 3 Biological indicator concentrations in soil samples taken at different depths for three water treatments

	5 days after the last irrigation Total coliforms (MPN g^{-1} dry soil)			10 days after last irrigation Total coliforms (MPN g^{-1} dry soil)		
Depth	Freshwater	WWTP	UASB-RBC	Freshwater	WWTP	UASB-RBC
0-15	339	8.95	70.45	15.48	19.23	<1
15-30	1.19×10^3	4.36	19.60	<1	<1	<1
30-45	5.67	1.98	199.00	<1	2.74	<1
45-60	38.90	133	33.38	<1	3.82	<1
	E. coli (MPN g^{-1} soil)			*E. coli (MPN g^{-1} soil)*		
0-15	<1	1.499	24.08	<1	<1	<1
15-30	3.13	1.195	6.92	<1	<1	<1
30-45	<1	<1	<1	<1	<1	<1
45-60	6.69	<1	2.74	<1	<1	<1
	Enterococcus (MPN g^{-1} soil)			*Enterococcus (MPN g^{-1} soil)*		
0-15	1.28×10^3	96.74	891	22.39	14.93	8.79
15-30	513	42.53	715	14.43	13.44	23.36
30-45	57.98	40.04	36.5	1.17	20.02	7.24
45-60	22.96	43.11	1.31x10^3	0	7.04	8.11

WWTP = Effluent of the existing activated sludge treatment plant before chlorination; UASB-RBC = Effluent of a pilot anaerobic-aerobic system consisting of a combined Upflow Anaerobic Sludge Blanket, UASB, reactor followed by Rotating Biological Contactors, RBC

Indicator pathogen counts in different soil layers for all treatments are shown in Table 3. Compared with total coliform values in freshwater (Table 1), the counts measured in soil 5 d after the last irrigation (Table 3) showed that soil was not free of this indicator pathogen. Rufete et al. (2006) measured a total coliform count in soil without additional treatment of around 104 colony forming units/g dry soil, which indicates that soils may have significant background of total coliforms. Regrowth of indicator pathogens in soil was reported by Gibbs et al. (1997) and high humidity was among the factors that helped growth of enteric bacteria (Entry *et al.* 2000, Rufete *et al.* 2006). The total coliform count decreased with time and soil dryness as shown 10 d after irrigation ceased (Table 3).

The *E. coli* did not survive in soil after irrigation; the *E. coli* count decreased considerably from maximum values of 24 MPN g^{-1} dry soil when irrigation was with UASB-RBC effluent (Table 3). Ten days after irrigation ceased, the *E. coli* count was < 1 MPN g^{-1} dry soil in all analyzed soil samples. Short survival times for *E. coli* were previously reported, e.g. Entry *et al.* (2005) did not detect *E. coli* in any soil sample after 1 d of application to soil. With respect to *Enterococcus*, there was a 2-3 log unit reduction in soil samples taken at all depths 5 d after the last irrigation, compared with counts in irrigation wastewater. Although *Enterococcus* was counted after the 10-day period following the last irrigation in all soil layers (except one), there was a considerable reduction in their concentration compared to soil samples 5 and 10 d after the last irrigation. Survival of these pathogens in soil layers is expected to decrease with time.

4 Discussion

A preliminary model was established to assess risk of infection and disease associated with wastewater irrigation of vegetables eaten uncooked (Shuval *et al.* 1997). This showed that irrigating with wastewater effluent, which met WHO (1989) guidelines with respect to fecal coliforms, would provide a safety factor of 1-2 orders of magnitude greater than that used by the US Environmental Protection Agency for acceptable microbial standards for drinking water. Indeed public health protection is a major concern; however, wastewater is a resource that should be fully exploited and irrational standards will limit its use. Moreover, protection of public health cannot be achieved solely at the treatment plant as pathogen regrowth does occur (Gantzer *et al.* 2001). Instead, health protection can be achieved using 'multiple barriers' (Carr *et al.* 2004) that interrupt the flow of pathogens to humans. In this approach, soil, wastewater treatment, irrigation technique, and human exposure control are all important in determining the fate of pathogens in wastewater. At the same time, the cost of wastewater treatment is reduced as soil and crops serve as biofilters (Haruvy 1997).

5 Conclusions

Pathogenic indicators measured on tomato plants and in soil irrigated with treated wastewater from an extended aeration treatment plant and an integrated UASB-RBC pilot plant showed that total coliforms and *Enterococcus* counts on nearly all tomato fruit samples and *E. coli* count on all fruit samples were < 1 MPN g^{-1} dry splant. Although secondary treated wastewater had indicator pathogenic counts of 2-5 log units, there was a considerable reduction in soil samples collected 5 and 10 d after the last irrigation. By 10 d after the last irrigation, all soil samples collected from all depths had < 1 MPN g^{-1} dry soil of *E. coli,* while total coliform counts ranged from less than 1 MPN to 19.23 MPN g^{-1} dry soil. With respect to the measured indicator pathogens, the results suggest that disinfection of reclaimed wastewater may not be necessary when proper agricultural practices are applied downstream of the treatment plant.

Acknowledgments

This research was part of the activities carried out on a CORETECH-EU ENCOMED funded project.

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Effect of Wastewater Application on Parsley Yield and Heavy Metal Accumulation in Soil and Plants

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Abstract

A glasshouse experiment was carried out to study the effects of applying wastewater on parsley yield and heavy metal accumulation in soil and plant. Two heavy metals, lead (Pb) and nickel (Ni), were added at different concentrations to irrigation water. The pots were sown with parsley seeds in a completely randomized design with three replications. The plants were irrigated with four concentrations of Pb and Ni, with treatments as follows: (T1) control; (T2) 600 mg Pb L^{-1} with 50 mg Ni L^{-1}; (T3) 300 mg Pb L^{-1} with 100 mg Ni L^{-1}; and (T4) 150 mg Pb L^{-1} with 250 mg Ni L^{-1}. Parsley seeds were sown on 1 July 2006, and germination started on 9 July 2006. The first cut was on 21 August 2006. Yellowing symptoms first appeared on plants in T4 – the highest Ni concentration. After one week of irrigation, yellowing symptoms appeared on plants in T3 – the medium Ni concentration – while low Ni concentration T2 plants showed no yellowing. Plant growth was rapid in the control and T2, compared with T3 and T4 treatments. Soil and plant analyses showed increased Ni concentrations in plants with increased soil Ni concentrations, revealing rapid transfer of Ni from soil to plant. Pb concentrations in plants progressively increased with increased soil Pb concentrations, although Pb movement in soil was slow. The applied amounts of Pb and Ni in irrigation water were calculated, and curves showed relationships between applied and measured concentrations in both soil and plants.

Key words: Parsley, heavy metal accumulation, lead, nickel, wastewater irrigation, Syria

1 Introduction

Wastewater is increasingly used for agriculture in various countries due to increasing water scarcity, increased population, and growing recognition of the value of wastewater and the nutrients contained. To protect public health and facilitate the use of wastewater and excreta in agriculture and aquaculture, in 1973, the World Health Organization (WHO) developed guidelines for wastewater use in agriculture and aquaculture (WHO 1973). After a thorough review of epidemiological studies and other information, the guidelines were updated in WHO (1989). The most recent revision took place in 2006 (WHO 2006). These guidelines have been very useful, and many countries have adopted them in their wastewater and excreta use practices.

It is estimated that within the next 50 years more than 40% of the world's population will live in countries facing water scarcity (Hinrichesen *et al.* 1988). Growing competition between agricultural and urban use of freshwater supplies, particularly in arid, semi-arid and densely populated regions, will increase pressure on this ever-scarcer resource.

The annual total water use in Syria is about 19×10^9 m^3 with a negative annual balance of more than 3×10^9 m^3, which is met by over-exploitation of groundwater. Of the total volume, about 87% is used for irrigation while 9% in domestic and 4% in industrial activities. The annual volume of wastewater generated in Syria is about 1×10^9 m^3, which could irrigate about 70,000 ha of cotton.

The environmental impacts of using wastewater in irrigation on soil and water pollution have rarely been studied in Syria. There are some available and accessible studies that may provide insight into possible contamination of crops irrigated with wastewater. We carried out a glasshouse experiment to study the effects of applying wastewater on parsley yield and heavy metal accumulation in soil and plants.

2 Material and methods

In this glasshouse study, known concentrations of two heavy metals, lead (Pb) and nickel (Ni), were added to tap water used to irrigate parsley. The experimental site was at the General Commission for Scientific Agricultural Research, Douma. Each pot contained 8 kg of soil collected from the Al-Tel area, with a loamy texture and cation exchange capacity of 40 cmolc kg^{-1} soil. The organic matter content was 1.24% and $CaCO_3$ 45%.

The field capacity of the soil was determined in four separate pots, and used to determine the maximum irrigation rate. Standard Ni and Pb solutions containing 1000 mg kg^{-1} were prepared from lead nitrate and nickel sulfate to prepare different Ni and Pb concentrations in irrigation water. The four irrigation water quality treatments were: (T1) control; (T2) 600 mg Pb L^{-1} with 50 mg Ni L^{-1}; (T3) 300 mg Pb L^{-1} with 100 mg Ni L^{-1}; and (T4) 150 mg Pb L^{-1} with 250 mg Ni L^{-1}.

The pots of the four water quality treatments were distributed in the greenhouse in a completely randomized design with three replications. The pots were seeded on 1 July and germination started on 9 July 2006. The soil moisture content was controlled by adding four different qualities of water using a balance to around 90% of field capacity. During the experiment, the vegetative parts of plants were cut twice at about 7 cm above the soil surface for analysis. Plant samples were dried to constant weight in an oven at 70°C, wet-digested and analyzed for Ni and Pb using the atomic absorption spectroscopy (AAS model: ZEEnit 700). Soil samples were air-dried and wet-digested using aqua regia for total analysis of Ni and Pb using atomic absorption spectrophotometer.

3 Results and discussion

There were no differences in germination percentage between treatments, which could be attributed to the low heavy metal concentrations in soil after a few irrigations. The first cut was on 21 August 2006, when parsley was sufficiently high for cutting and some toxicity symptoms had appeared on plants receiving the highest Ni concentration. After a week, Ni toxicity symptoms appeared on plants receiving the second highest Ni concentration. The average dry weights of the plants (first and second cut) decreased with increased Ni concentration in irrigation water (Fig. 1), clearly showing the effect of Ni toxicity on parsley production. This was evident in toxicity symptoms on leaves, especially at the end of the experiment.

There was a good correlation of Ni concentrations between soil and plants (Fig. 2). The slope of the regression (0.9082) showed high translocation of Ni from soil to plant tissue. The highest Ni concentration in soil (~300 mg kg^{-1}; Fig. 2) was almost three times the maximum safe soil content of Ni in soil (WHO 2006). There was a good correlation of Pb concentrations between

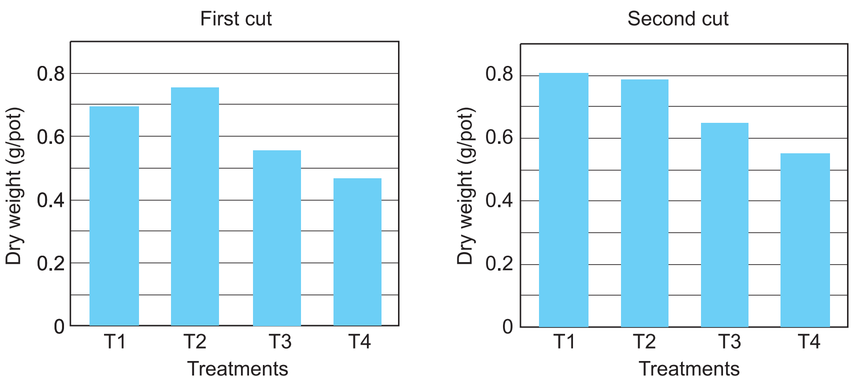

Fig. 1 Average dry weight (g/pot) of parsley at first and second cuts

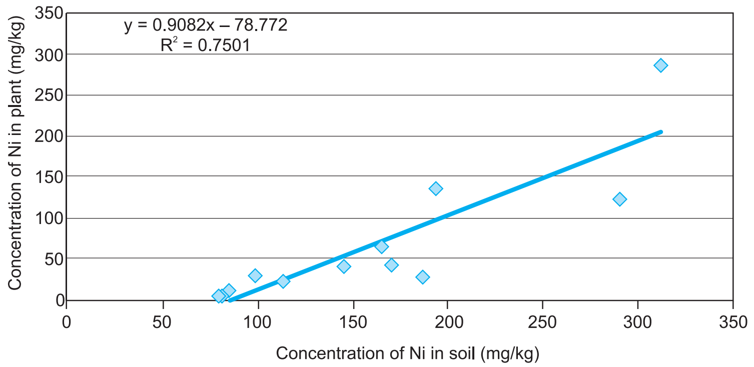

Fig. 2 Concentration of Ni in plant and soil at first cut

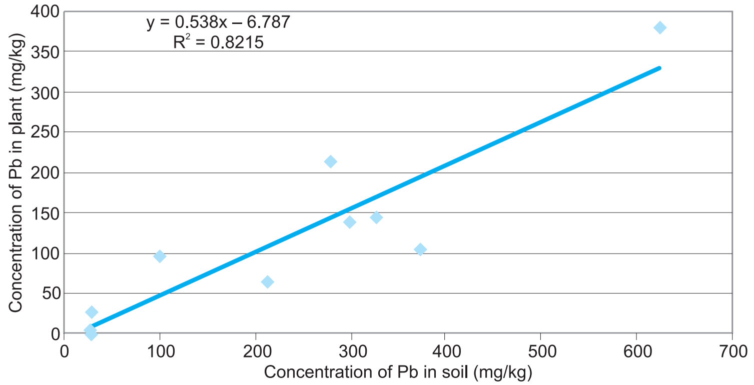

Fig. 3 Concentration of Pb in plant and soil at first cut

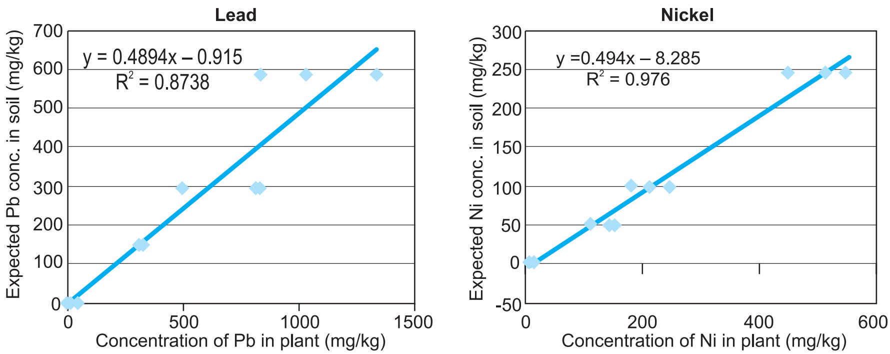

Fig. 4 Concentrations of Pb and Ni in plant and soil at second cut

soil and plants (Figure 3). The slope of the regression (0.538) showed that translocation of Pb from soil to plant tissue was less than for Ni. The highest Pb concentration in soil (~600 mg kg^{-1}; Figure 3) was almost six times the maximum safe soil Pb content (WHO 2006). The Ni and Pb results in soil were due to relatively high cation exchange capacity (40 cmolc kg^{-1}) and high $CaCO_3$ (45%), and so might not be applicable to other soils.

There were better correlations between concentrations of Ni and Pb in plants and the expected soil concentrations from applying irrigation water at the time of the second cut than for the first cut (Figure 4). The slopes for Ni and Pb were almost the same: 0.4894 and 0.4946, respectively. The amounts of Pb and Ni added to the soil of each pot were calculated from concentrations of each in irrigation water and the amount of water added. The highest Pb concentration in irrigation water was 600 mg L^{-1}, which is 120 times the concentration allowed in irrigation water (5 mg L^{-1}; WHO 2006). Highest Ni concentration in irrigation water was 250 mg L^{-1}, 1250 times the concentration allowed in irrigation water (0.2 mg L^{-1}; WHO 2006; SSC 2752, 2003). Such high concentrations of heavy metals were added to irrigation water to monitor the toxicity symptoms of Pb and Ni in parsley and to see the long-term effects of using wastewater containing heavy metals on soil concentrations and the amount transported to plants, which eventually could have health impacts. Increasing amounts of Pb were absorbed by parsley with increased soil concentration or amounts of Pb added by irrigation water (Figure 5a). However, the percentage absorbed by parsley or transported to vegetative parts of plants (except the control because of low Pb levels in vegetative parts) decreased with the increased amounts of Pb added to soil by irrigation water (Figure 5b).

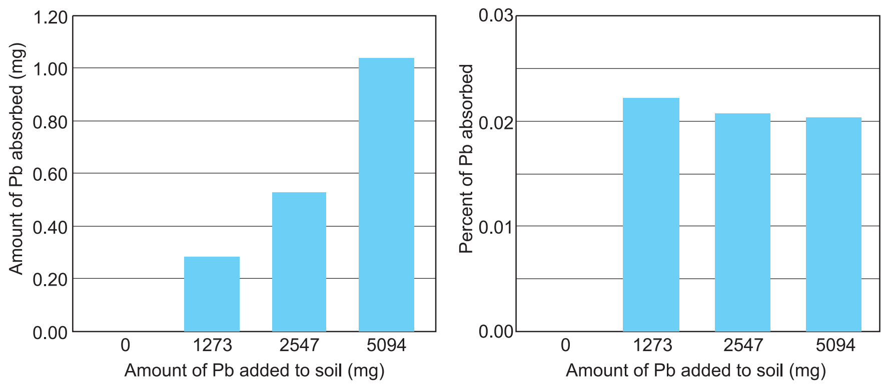

Fig. 5 Amount of Pb added to the soil with different irrigation treatments vs. the amounts absorbed by the plant

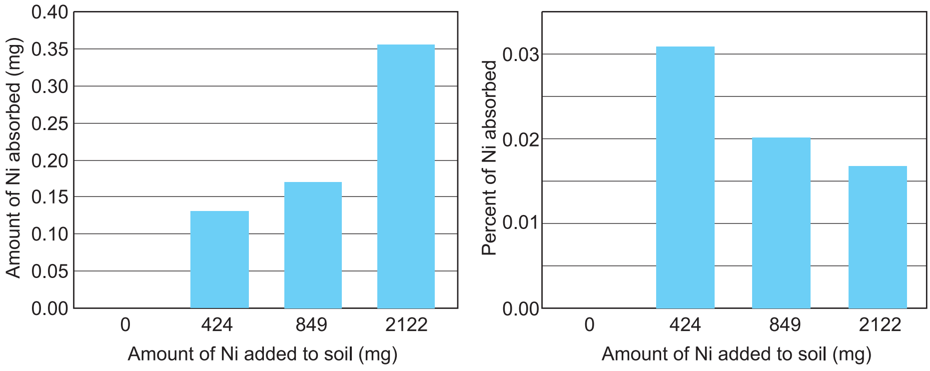

Fig. 6 Amount of Ni added to the soil with different irrigation treatments vs. the amounts absorbed by the plant

The amount of Ni absorbed by parsley and the percentage absorbed (Fig. 6a, b) showed the same trend as for Pb, but the decrease in the percentage of Ni absorbed by the plant was clearer. This can be attributed to the very high Ni concentration in soil.

Although the highest Pb concentration in studied soil reached six times the maximum concentration in the soil recommended by WHO (2006), there were no toxicity symptoms on parsley. However, Ni toxicity symptoms appeared on parsley when its concentration in soil reached three times the maximum recommended by WHO (2006). This might be attributed to the method of soil digestion used, soil pH, and other soil properties, in addition to plant species/variety. These topics require further study.

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Effect of EDTA on the Growth and Phytoremediative Ability of Wheat Grown in Heavy Metal Contaminated Soil

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Abstract

Phytoextraction has received increasing attention as a promising, cost-effective alternative to conventional engineering-based remediation methods. In order to enhance the phytoremediative ability of green plants, chelating agents are often added to the soil. This study investigated the effects of various rates (0, 2, 4, 8 mmol kg^{-1}) of ethylene diamine tetraacetic acid (EDTA) application on metal availability in contaminated soils and on the ability of a wheat variety 'Auqab-2000' to accumulate lead (Pb) from contaminated soils. Application of EDTA at 8 mmol kg^{-1} caused a significant depression in the biomass yield, photosynthetic rate and transpiration rate of wheat. Results indicated that without EDTA, very little Pb was absorbed by wheat plants; however, adding EDTA to soils increased the solubility of Pb and its uptake by wheat plants.

Key words: Lead, ethylene diamine tetra-acetic acid, wheat, photosynthesis, Pakistan

1 Introduction

Rapid industrialization and increased exploration of natural resources in many developed countries, and indiscriminate use of raw city effluent for irrigation in developing countries has accelerated the addition of heavy metals onto soils. Lead (Pb) is one of the most widespread and persistent metal pollutants in soils (Kumar *et al.* 1995). At toxic levels, Pb may reduce plant growth by disturbing chlorophyll formation, decreasing photosynthetic activity (Ruley *et al.* 2006) and eliminating enzymatic activity (Wierzbicka *et al.* 2007). Moreover, its entry into the food chain from contaminated soils and waters results in severe toxicity to animals and humans. An increasing demand for uncontaminated agricultural land has emphasized the need to remediate contaminated soils. These soils must comply with legislation to limit the transfer of heavy metals form soil into potential food crops.

Strategies commonly used to remediate heavy metal contaminated sites include leaching with acids and chelators or by adding soil amendments such as calcium and magnesium carbonates, and calcium oxides to decrease the availability of metals to plants. However, this approach and others are often costly and disruptive to the site (Begonia *et al.* 2005) affecting soil properties viz. texture, organic matter content and microorganisms. Recently, phytoremediation, especially phytoextraction, has received increasing attention as a promising, cost-effective alternative to conventional engineering-based remediation methods (Salt *et al.* 1998). The success of phytoextraction depends on metal concentrating in plant shoots, adequate plant yield and a bioavailable fraction of heavy metals in the rooting medium (Grčman *et al.* 2001).

Lead forms insoluble precipitates so is usually poorly bioavailable (McBride, 1994). In order to enhance the availability of Pb in soil and increase its translocation from root to shoot, chelating agents such as ethylene diamine tetraacetic acid (EDTA) may be used (Meers *et al.* 2005). A large number of investigators have used EDTA to enhance heavy metal uptake by green plants. However, very limited information is available regarding the phytotoxic effects of EDTA during chemically enhanced phytoextraction. This study was undertaken with the objectives: (i) to assess the effects of EDTA on the growth, gas exchange features, and ionic composition of wheat; and (ii) to evaluate the role of EDTA in enhancing solubility and the ability of wheat to uptake Pb from a contaminated soil.

2 Materials and methods

2.1 Study area

Soil used in the experiment was collected from an agricultural field irrigated with untreated city sewage located at village 217-RB, Kajlianwala, in Faisalabad, Pakistan. The soils in these parts of Pakistan have developed from alluvium derived from the Himalayas mountain ranges and transported to the Indus River and its tributaries during the late Pleistocene age.

2.2 Basic physico-chemical characteristics of the studied soil

Soil samples were analyzed for saturation paste pH (pH_s), pH of soil to water ratio ($pH_{1:2}$), saturation paste extract EC (EC_e), organic matter (OM), lime content ($CaCO_3$), soil texture, and cation exchange capacity (CEC) following methods described by the US Salinity Laboratory Staff (1954) and Page *et al.* (1982). The total concentrations of metals (Cu, Mn, Pb and Zn) in soil were determined by digesting soil samples in a mixture of HCl/HNO_3 (McGrath and Cunliffe 1985). AB-DTPA extractable metals (Cu, Mn, Pb and Zn) in soil samples were determined according to the method described by Soltanpour (1985). Total concentrations and AB-DTPA extractable metal concentrations in soils samples were determined using an atomic absorption spectrometer (Model Thermo S-Series).

2.3 Pot experiment

The experiment was conducted in a wire-house with an iron net-covered roof. The sides of the house were open with only iron wire screens and no control of temperature and relative humidity. Sandy clay loam soil, spiked with Pb (500 mg kg^{-1}), was used for this experiment. Before the air-dried soil (11.5 kg) was put into experimental pots, it was fertilized with 75 mg N kg^{-1} soil as urea, 100 mg P kg^{-1} soil as single super phosphate, and 70 mg K kg^{-1} soil as potassium chloride. Ten wheat seeds per pot were sown on November 15, 2006, and five seedlings per pot were maintained up to booting stage. Ten days before harvesting, EDTA was applied at concentrations of 0 (control) 2, 4 and 8 mmol kg^{-1} dry soil in solution form on the soil surface. Treatments were replicated three times in a completely randomized design; thus, 12 pots were used. Two hours before harvesting, measurements of net CO_2 assimilation rates, transpiration rates and stomatal conductance rates were made on flag leaves of three randomly selected plants from each pot.

After taking readings of gas exchange features, plants were harvested one centimeter above the soil surface. After its oven-dried weight was recorded, the plant material was ground and a portion of 0.5 g was digested in a diacid mixture of nitric acid and perchloric acid (3:1) at 150°C (Miller 1998). Concentrations of Pb, Cu, Mn, Zn, and phosphorus (P) in the shoot digest were determined with the help of an atomic absorption spectrometer (Model Thermo S-Series) and a spectrophotometer (Model Thermo Electron Corporation). Soil samples, taken from the pots immediately after the plants were harvested, were analyzed using flame atomic absorption spectrometry to determine the AB-DTPA-extractable and deionized-water (DI)-extractable Pb. The results were analyzed using MINITAB version 14 software. The data gathered were analyzed statistically following the analysis of variance technique (ANOVA). The differences were statistically significant when the P-value was less then 0.05. The graphs were plotted using Microsoft Excel.

3 Results

3.1 Effect of EDTA on dry biomass, gas exchange features, and shoot Pb concentration

The effect of the amendments on shoot dry matter is presented in Fig. 1A. The data illustrate that shoot dry matter increased with the application of

EDTA up to 4 mmol kg^{-1} ; however, application of EDTA at 8 mmol kg^{-1} significantly decreased the dry matter of wheat. Regarding photosynthetic and transpiration rates, both the features were significantly affected by EDTA (Fig. 1B and 1C). A maximum photosynthetic rate of 16.10 µmol CO_2 m^{-2} s^{-1} was recorded in wheat plants where EDTA was applied at 4 mmol kg^{-1} . By contrast, a minimum photosynthetic rate of 9.06 µmol CO_2 m^{-2} s^{-1} was noted with an EDTA application of 8 mmol kg^{-1}. Similarly, plant transpiration significantly decreased when EDTA was added to soil at 8 mmol kg^{-1}. Concentrations of Pb in wheat shoots are depicted in Fig. 1D. A maximum shoot Pb concentration (reaching a level of 390.07 µg g^{-1}) was recorded with the highest rate of EDTA application of 8 mmol kg^{-1}. Meanwhile, a minimum Pb concentration (14.57 µg g^{-1}) in wheat shoots was observed under control treatment (without EDTA).

3.2 Effect of the amendments on water soluble Pb in soil after wheat harvest

Water soluble Pb in soil reached a maximum mean Pb concentration of 224.88 mg kg^{-1} when EDTA was applied at 8 mmol kg^{-1} (Fig. 2). Meanwhile, a minimum value of 3.93 mg $kg^{-1}$for deionized-water-extractable Pb was recorded with the control treatment. The concentration of water-soluble Pb increased with EDTA applications.

4 Discussion

In this study, EDTA was used to enhance Pb phytoextraction. Chelating agents added to soil form soluble complexes with metals in soil solution and could help release metals from the soil solid phase. As expected, increasing the EDTA concentration increased the soluble concentration of Pb. A 34- and 43-fold increase over the control treatment was observed for soluble concentrations of Pb with the application of 2 and 4 mmol EDTA kg^{-1} soil, respectively. However, when EDTA was applied at 8 mmol kg^{-1}, the concentration of Pb in the soil solution was 71 times higher than the control treatment. The ability of EDTA to enhance the release of Pb from insoluble or sparingly soluble compounds could be attributed to its higher binding capacity for Pb, as observed in previous studies (Blaylock *et al.* 1997) and its resistance to biodegradation (Lombi *et al.* 2001). Application of EDTA, especially at high rates, significantly reduced the shoot biomass of wheat plants compared with those under the control treatment. EDTA applications at 2 and 4 mmol kg^{-1} showed no adverse impact on shoot dry matter production. Without any amendment, shoot dry matter was 27.26 g pot^{-1}, which decreased to 24.51 g pot^{-1} when EDTA was applied at 30 mmol kg^{-1}. It has been proposed that during chelating-agent-enhanced phytoextraction, plant biomass is influenced by chelating agents – either directly due to toxicity at high concentrations, or indirectly through the agents' ability to enhance the availability of metals in the growing media to toxic levels. In this study, either mechanism might have lowered shoot biomass, especially in the case of EDTA applications at 8 mmol kg^{-1}.

The application of EDTA up to 4 mmol kg^{-1} significantly increased photosynthetic rates compared with control plants. The Pb-EDTA complex is known to be less phytotoxic than free Pb(II) (Vassil *et al.* 1998), and applying EDTA could help increase availability of certain plant nutrients to affect better plant growth (Hovsepyan and Greipsson 2005). However, applying EDTA at 8 mmol kg^{-1} resulted in significantly lower plant photosynthetic and transpiration rates compared with those under the control treatment. This may be due to phytotoxicity caused by high application rates of EDTA (Evangelou *et al.* 2006). Moreover, data revealed that applying EDTA at 8 mmol kg^{-1} resulted in significantly high shoot Pb concentrations, which might have decreased plant photosynthetic rates.

The accumulation of Pb in plants from soil relies on an adequate concentration of Pb in a soluble form in soil, and on the uptake of the metal by plant roots and its translocation to shoots (Luo *et al.* 2006). In the present studies, adding EDTA to soil significantly increased the concentration of Pb in shoots compared with those under control treatment (Fig. 1 D). Applying EDTA at 2, 4 and 8 mmol kg^{-1} significantly ($p<0.0001$) increased the concentration of Pb in shoots by 3.11-, 3.31- and 5.72-fold, respectively over that in the shoots of control plants. An increase in the uptake of Pb induced by applying EDTA could be explained by its effect on enhancing the solubility of Pb (Fig. 2) and the absorption of the Pb-EDTA complex by plants (Vassil *et al*. 1998). The increase in Pb levels from adding EDTA was not as high as that stated by other investigators (Huang *et al.* 1997). Huang *et al.* (1997) reported a more than 100-fold increase in Pb concentrations in plant shoots following the application of EDTA. Differences in these results could be attributed to smaller amounts of soil used in experiments as well as different plant species used: Huang *et al.* (1997) used only 350 g soil, which might have resulted in more contact between soils and roots, leading to higher Pb uptake.

5 Conclusions

EDTA at low application rates did not affect plant biomass; however, substantially lower shoot biomass was observed when EDTA was applied at 8 mmol kg^{-1}. EDTA increased Pb concentrations in soil solutions by the end of experiment and an increase in the solubility of Pb was dependent upon the rate of EDTA applied to the soil.

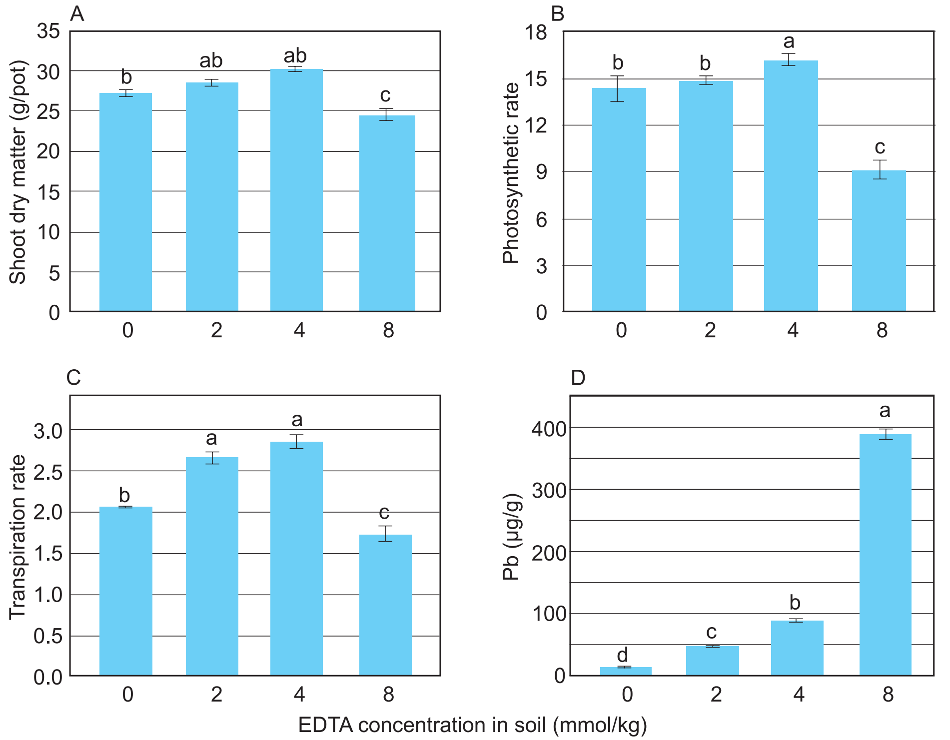

Fig. 1 Effect of applying EDTA to soil on (A) shoot dry matter, (B) photosynthetic rate (µmol m^{-2} s^{-1}), (C) transpiration rate (µmol CO_2 m^{-2} s^{-1}), and (D) Pb concentration in shoots of wheat. Error bars represent ± SE of replicates. Significant at p = 0.05

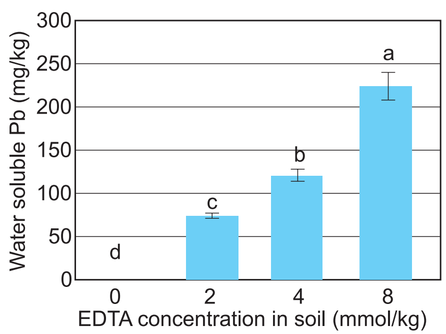

Fig. 2 Water soluble Pb in soil after the application of EDTA. Significant difference at p = 0.05

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How Irrigating with Treated Wastewater Cumulatively Affects the Chemical Properties of a Sandy Soil

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Abstract

The aim of this work was to study how irrigating with treated wastewater cumulatively affects the chemical properties of a sandy soil through three periods (nine months, two years and four years). The olive tree (*Olea europaea* L.) was used as a test plant. Soil samples were collected before irrigation using treated wastewater, as well as each year after the harvest. Soil chemical characteristics were evaluated by measuring pH, soil electrical conductivity (EC) and levels of K, P, Na, Cl, Zn, Mn, Cd and Pb. Irrigation with treated wastewater improved soil fertility, by increasing available plant nutrients (K and P) and decreasing pH. Irrigation with treated wastewater at an annual rate of 5000 m^3 ha^{-1} in a sandy soil provided the equivalent of 50 kg P ha^{-1} and 190 kg K ha^{-1}. Data showed that irrigation with treated wastewater caused a significant increase in salt (Na and Cl) and metal (Zn and Mn) contents throughout the entire period of the experiment. However, contents of other metals (Cd and Pb) remained below the detection limits.

Key words: Treated wastewater, irrigation, sandy soil, mineral nutrients, soluble salts, heavy metals.

1 Introduction

Sandy soils, that are poor in mineral and organic colloids, have low fertility as determined by low water retention and a shortage of macro- and micronutrients (Weber *et al.* 2006). Good agricultural practices involve frequent applications of organic fertilizers, both conventional and non-conventional (Weber *et al.* 2006). Irrigation with treated wastewater (TWW) improves soil fertility, tree growth and crop production (Shende 1985, Coppola *et al.* 2004). Reusing TWW can therefore replace or reduce the use of chemical fertilizers in agriculture (Gil and Ulloa 1997, Coppola *et al.*

2004). Beside the listed benefits, reusing TWW can have controversial impacts, especially because of potential risks from associated toxic metals (Feigin *et al.* 1991, Pescod 1992, Som *et al.* 1994, Gupta *et al.* 1998, Brar *et al.* 2000, Yadav *et al.* 2002). However, the most harmful effects are from high salt concentrations causing soil salinization (Narwel *et al.* 1993) and from heavy metal accumulations causing soil and underground water pollution (Mapanda *et al.* 2005). The reuse of TWW in Tunisia, which can satisfy increasing water requirements, constitutes a tool for preserving water resources. In Tunisia, municipal wastewater is of domestic and industrial origin and is typically treated at secondary level using biological processes (Bahri 2002). These processes consist of eliminating the biodegradable material by transforming it into microbial residues.

Several studies have addressed how irrigation using saline waters affects soil salinization (Bustan *et al.* 2005, Tedeschi and Dell' Aquila 2005); how irrigating with TWW affects the chemical properties of clay soils (Heidarpour *et al.* 2007); and how reusing TWW affects heavy metal contents in soil (Yadav *et al.* 2002, Mireles *et al.* 2004, Mapanda *et al.* 2005, Rattan *et al.* 2005). However, only a few researches have focused on how irrigation using TWW affects the fertility of sandy soils (Patterson and Chapman 1998) and salt concentrations (Bredai 1996, Lazarova 1999).

The objectives of this study are: (i) to show how irrigation using TWW cumulatively affects the chemical properties of sandy soil; (ii) to evaluate the importance of TWW in sandy soil fertility; and (iii) to anticipate the risk of soil salinization and heavy metals contamination over the long term.

2 Materials and methods

2.1 Field experiment

The experiment was carried out at the experimental farm of El Hajeb in the region of Sfax (34° 43 N, 10° 41 E), in the central eastern part of Tunisia. The experimental field is characterized by sandy soil with 84.4% of sand, 9.8% of clay and 5.8% of silt. The average annual rainfall is 211 mm, which occurs mostly in the fall and in winter. The average annual temperature is 21.7°C. The plot experiment contained ten randomized olive trees planted at 24 × 24 m spacing and irrigated using TWW with a continuous drip system at an annual rate of 5000 m^3 ha^{-1}.

2.2 Chemical characteristics of TWW

Treated wastewater has a domestic and industrial origin and is typically reclaimed at the secondary level using biological processes. These processes consist of eliminating biodegradable material by transforming it into microbial residues. TWW used for long-term irrigation was neutral and marginally saline. Detailed chemical characteristics of the wastewater are given in Table 1.

Table 1 Chemical characteristics of treated wastewater (ONAS 2003)

Characteristic	Unit	Treated wastewater
pH		7.60
EC	mS cm^{-1}	6.30
Salinity	g L^{-1}	4.66
Total P	mg L^{-1}	10.3
K^+	mg L^{-1}	38
Na^+	mg L^{-1}	470
Cl^-	mg L^{-1}	1999
Pb^{2+}	mg L^{-1}	< 0.004
Cd^{2+}	mg L^{-1}	< 0.004
Zn^{2+}	mg L^{-1}	0.42
Mn^{2+}	mg L^{-1}	0.5
COD	mg L^{-1}	73
BOD	mg L^{-1}	22

2.3 Soil sampling

The field experiment was divided into three completely randomized blocks. Composite soil samples were collected in triplicate from each block at 0-80 cm depth before irrigation (February 2003) and after the harvest every year (November) over three crop seasons. The soil samples were brought to the laboratory for analysis.

2.4 Mineral analysis

Previously mixed soil samples were air-dried at room temperature, ground, crushed and passed through a 2 mm sieve. Soil pH and electrical conductivity (EC) were determined using methods as described by Sparks et al. (1996). The pH was measured in suspension at a soil:water ratio of 1:2.5 with a pH meter (JENWAY). EC was measured in a saturated paste using a conductivity meter (MC 226). Available P was determined using the Olsen method on calcium carbonate soil extract (Olsen *et al.* 1954). K and Na contents were determined on ammonium acetate soil extract (Richards 1954) using a flame photometer. Cl was determined by titration with AgNO3. Metals (Zn, Mn, Cd, and Pb) were extracted using an acid digestion method (Li and Thornton, 1993) and determined using an atomic absorption spectrophotometer (Perkin Elmer A Analyst 300).

2.5 Statistical analysis

Results were analyzed using Super ANOVA, considering the time period as the independent variable. All statistical analyses were carried out with the program SPSS 10 for Windows. Significant statistical differences of all variables between the years were established by an LSD test at $p < 0.05$.

3 Results and discussion

3.1 Soil pH

The average pH values at the beginning of the experimental period were 7.8. The initial pH values dropped significantly to 7.4 at the end of study period, which is related to the effects of using treated wastewater. This finding is consistent with those reported by several studies (Narwel *et al.* 1993, Singh and Verloo 1996). The slightly alkali values were related to the high buffering capacity of south Tunisian soil rich in limestone. Data showed that irrigating with TWW caused a reduction in the alkalinity of sandy soil, confirming the results of previous studies in soils amended with domestic sewage effluents and liquid sludge (Yadav *et al.* 2002, Mantovi *et al.* 2005, Rattan *et al.* 2005).

3.2 Soil electrical conductivity (EC)

The values of EC were quite low at the beginning of the experimental period, ranging from 0.1 to 0.14 mS cm^{-1}. Yet, a significant increase was found nine months after irrigation with TWW. These values went up to 3.4 mS cm^{-1} in deep soil at the end of the trial period (Table 2). The significant increase in EC was due to salt input from TWW, as described previously (Gil and Ulloa 1997, Xanthoulis and Kayamanidou 1998, Massena 2001). There was an increase in EC values in the upper soil layer from drip irrigation over the study period (Table 2). There was an upward movement of water from evaporation, which resulted in an accumulation of salts at the soil surface. This result is in agreement with other researchers' results (Choi and Suarez Rey 2004, Assadian *et al.* 2005, Al-Zu'bi 2007, Heidarpour *et al.* 2007). The high EC values reported at depth can be explained by salts leaching (Johnson *et al.* 1989, Tedeschi and Dell'Aquila 2006). The highest EC value, found at 60-80 cm at the end of experimental period indicates a risk of soil salinization at depth. A soil having EC of the saturated paste extract $\geq$ 4 mS cm^{-1} is called a saline soil. So, continued long-term irrigation with TWW could cause further soil salinization at depth, confirming a previous study (Narwel *et al.* 1993).

Table 2 Effect of wastewater irrigation on soil chemical properties

Time/ soil depth	EC (mS cm^{-1})	K (ppm)	P (ppm)	Na (ppm)	Cl (me L^{-1})	Zn (ppm)	Mn (ppm)
Initial							
0-20	0.14a	190a	38.40a	104a	8.0a	29a	143a
20-40	0.11a	170a	34.40a	61a	3.0a	28a	142a
40-60	0.10a	135a	36.00a	114a	5.0a	28a	120a
60-80	0.14a	70a	26.40a	142a	9.0a	28a	90a
Nine months							
0-20	0.47a	240b	72.00b	160b	13.70b	29a	145a
20-40	0.16a	240b	67.20b	100b	9.60b	25a	155b
40-60	0.42a	230b	76.80b	165b	14.70b	28a	125b
60-80	0.81a	220b	55.20b	175b	19.30b	28a	95b
Two years							
0-20	0.60a	400c	86.40c	200c	14.30c	35b	147b
20-40	0.19a	350c	69.00c	133c	12.60c	39b	158b
40-60	0.97a	300c	76.80c	227c	20.40c	30b	128b
60-80	1.71a	270c	74.00c	250c	25.60c	30b	97b
Four years							
0-20	0.87a	750d	109.20d	500d	28.30d	41c	158c
20-40	0.59b	600d	109.20d	410d	22.50d	45c	165c
40-60	3.01c	350d	146.00d	650d	28.30d	31c	138c
60-80	3.49d	300d	126.00d	640d	36.40d	33c	98b

Different letters within columns indicate significant difference ($p<0.05$)

3.3 Soil sodium and chloride concentrations

In the initial soil samples, sodium (Na) concentrations ranged from 61 to 142 ppm and chloride (Cl) from 3 to 9 me L^{-1} (Table 2). An appreciable increase in concentrations of Na and Cl was found throughout the whole experiment at all depths, as described previously (Bredai 1996). The yearly significant increase in Na and Cl concentrations in the soil may be related directly to a high concentration of soluble salts in the TWW, which is mainly of domestic origin and rich in detergents. Similar results were shown by Lazarova (1999). The fact that the highest Na and Cl concentrations were found at depths of 40-80 cm throughout the period of the experimental trials is the result of Na and Cl leaching (Johnson *et al.* 1989, Tedeschi and Dell'Aquila 2006). We can conclude that the rate of salt accumulation changes with time and could cause soil accumulations of Na and Cl at high levels implying soil salinization (Schofield *et al.* 2001).

3.4 Soil nutrient concentrations

At the beginning of the experimental period, soil nutrient concentrations ranged from 70 to 190 ppm and from 26.4 to 38.4 ppm, respectively for potassium (K) and phosphorus (P) (Table 2). Soil K and P concentrations increased at all depths over the study period, due to TWW effects and confirming the results of previous studies (Emongor and Ramolemana 2004; Heidarpour *et al.* 2007). There was a progressive increase in P and K levels in soil over time.

Soil K concentrations were lower than those reported by Melero *et al.* (2006) in fertilized soil with 30 t ha^{-1} of compost. Nevertheless, P values were higher than those reported by Bedbabis (2002) in fertilized soil with decomposed compost. Data showed that irrigation using TWW provided complementary potassium fertilization and constituted a phosphorus fertilizer source. The TWW contained 38 mg L^{-1} of K and 10 mg L^{-1} of P. Consequently, it may provide annually 190 kg ha^{-1} of K and 50 kg ha^{-1} of P. These results are consistent with those reported by Pescod (1992).

3.5 Soil metal ion concentrations

At the beginning of the experiment, metal concentrations ranged from 28 ppm to 29 ppm and from 90 ppm to 143 ppm, respectively for zinc (Zn) and manganese (Mn). According to the result reported by Weber et al. (2006), the soil was classified as one with a natural concentration of Zn, although concentrations were lower than those reported in the UK guidelines for agriculture (Muchuweti *et al.* 2006). The Zn and Mn concentrations found throughout the study period were within the range values reported by Adriano (1986) in agricultural soil. The lowest Zn concentrations were probably due to metal precipitation at a basic pH. The basic pH facilitates heavy metal precipitation and therefore maintains levels at concentrations without risk (Zekri *et al.* 1997).

A significant small increase in Mn and Zn concentrations was found in subsurface soil at the end of the experiment. This may be attributed to cumulative addition of these metals to the soil through irrigation, as described previously (Bahri and Hommane 1987). The highest concentration of these metals found in subsurface soil was probably a result of complexation with organic matter, confirming a previous study by McGrath and Lane (1989). The lowest Zn and Mn concentrations found in the deepest layer (60-80 cm) may have been due to restricted metal mobilization under a high alkaline pH in the first three soil layers.

Soil cadmium (Cd) and lead (Pb) concentrations were lower than the detection limit of 0.004 ppm. These concentrations remained well below the toxic limits of 3 ppm for Cd and 300 ppm for lead (Mapanda *et al.* 2005). Data showed that TWW did not cause an accumulation of heavy metals, due to lower concentrations in water. In a similar study, irrigation with reclaimed water and biosolid application did not affect the trace element contents of soil (Bahri 2002; Montovi *et al.* 2005).

4 Conclusions

This study gives preliminary results describing the implications of TWW on sandy soil in the medium term. The experiment indicated that irrigation using TWW on sandy soil improved mineral fertility by decreasing soil pH and significantly increasing available P and K. Data showed that TWW can be considered not only as a P fertilizer source, but also as a complementary source of K fertilization for sandy soil. Annual application rate of 5000 m^3 of TWW provides the equivalent of 50 kg ha^{-1} of P and 190 kg ha^{-1} of K.

Irrigating with TWW caused significant increases in EC, Na and Cl concentrations in sandy soil. Increased salt concentrations were due to elevated salinity levels in the TWW and continuous irrigation could lead to soil salinization in the long term. These salt concentrations could exceed acceptable limits for olive tree production. Further experiments could help determine the harmful effect of sodium and chloride in olive tree growth, development and yield. A small increase in heavy metals (Zn and Mn) was found in soil irrigated with TWW throughout the whole experimental period. Meanwhile, Pb and Cd concentrations were below detection limits in the soil. The concentrations of all metals remained well below the Tunisian regulatory limits for irrigation with TWW, but continuous irrigation with TWW over the long term could potentially result in high levels of Zn and Mn in the soil.

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Socio-Economic Impacts of Changing Water Strategies on Farming Systems in the Jordan Valley

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Abstract

Jordan's scarce water resources are facing higher demands due to population growth and increasing competition between agriculture and other economic sectors. This study aims to assess the socio-economic impacts of selected strategies for irrigation water on farming systems in the Jordan Valley. The first strategy is taking water away from agriculture and providing it to other sectors, best reflected in the case of the northern Jordan Valley. The second strategy is increasing the amount of water provided to agriculture (treated wastewater), which is a future prospect for the southern Jordan Valley. A third strategy is to make farmers contribute to the costs of treating wastewater, which applies to the whole Jordan Valley. The model-based prognoses for the representative farming systems showed that changes in both water availability and prices would always lead to changes in cropping patterns. Moreover, increasing prices for irrigation water as well as decreasing water availability would have significant negative impacts on the obtainable farm income, which endanger the survival, at least of farming systems, for the lower end of the family income scale. Increasing water availability, e.g. by incorporating recycled water, would positively impact the farm income of all farming systems classes, especially the high income classes.

Key words: Irrigation, water availability, socio-economics, farming systems, Jordan, Jordan Valley

1 Introduction

Water scarcity is a major problem in Jordan and originates from the country's meager water resources, most of which emanate from outside of its borders and are shared with other countries. Reasons for the growing extent of the problem are a high rate of population growth and a growing demand for water from other economic sectors, which exerts extra pressure on water use and allocation. This rise in demand constitutes a highly controversial situation, since it exerts pressure for freshwater to be withdrawn from agriculture, thus limiting farming potential to meet the simultaneously rising demand for food production and economic growth in rural areas (Wolff and Doppler 2002).

Water stands out as one of the scarcest production factors that contribute to family income and living standards in the Jordan Valley. The study focuses on the irrigation area of the Jordan Valley Authority (JVA), which plays a central role in allocating Jordan's water resources, particularly with regard to water use in irrigated agriculture. In this task, JVA's centralized management of the predominant part of available water has to cope with a diverse range of individual farming systems.

The basic hypothesis of this study was that the quantity and price of irrigation water affect all levels of socio-economic systems on a vertical dimension (agriculture - farming systems - village - watershed - nation - region) as well as ecosystems (Doppler 1999). Socio-economic analyses and modeling focused on family resources and activities as parameters for the description and prognosis of the social situation and economic success of farming systems in the study area. The specific objectives were to:

- Understand and explain (a) differences between farming systems with irrigated agriculture and (b) the decision making of farming families on the use of their resources
- Compare the development of different socio-economic classes of farming systems with respect to resource availability, use and efficiency and to analyze the reasons for these differences
- Measure the impact of future strategies for water availability and pricing on living standards of different socio-economic groups of families

2 Information base and methodology

The research methodology followed the farming systems approach, which considers the complex relations between agriculture and off-farm and household activities in achieving the families' objectives. This implies analyses of family resources and activities as well as a socio-economic analysis of living standards. The irrigation area supplied by the Jordan Valley Authority (JVA) in the Jordan Valley was chosen because of its unique characteristics as an area with intensive agricultural activities. In addition, it is a water-dependent watershed with zones of different water qualities available for agriculture. Information was derived from both primary and secondary sources. Micro-level data originated from a farm-family survey with standardized questionnaires investigating 141 farming systems. The selection of the interview partners followed a stratified random sampling design that was based on an administrative subdivision of the JVA's irrigation scheme. Complete lists of irrigation perimeters were used for the random selection of interview partners via their areas of irrigated land.

A subdivision of the farming systems in the sample was required in order to obtain farming systems classes with an acceptable degree of internal homogeneity. The complexity of the farming systems anticipated the use of a small set of criteria or even a single criterion for classification. Consequently, a cluster analysis based on several quantitative criteria on resource availability and socio-economic success was used. Analyses of the identified farming systems classes covered their past development and current situation and provided the basis for assessing future development.

Dynamic linear programming models were used to estimate future developments and impacts from water strategies. Such models were established and calculated for the centroid farming system in each class, i.e. the farming systems that showed the least absolute value of deviation from the medians of the classification criteria in their class. A further, spatial distinction was made showing the location of these farming systems, in anticipation that the development of water availability would differ in different parts of the study region. In the northern part of the JVA's irrigation area, a likely development is decreasing amounts of water available for irrigation due to water re-allocation, while in the middle and southern part, water availability may increase as water is recycled from urban areas. These differences in future expectations found their expression in the modeling process through consideration of the centroid farming systems of the four classes in the respective areas. The quantification and analyses of impacts from increasing water prices reverted to the centroid models of the total sample in all areas of the study region.

3 Results and discussion

Results of the study indicated four major classes of farming systems, which have different initial situations and will be affected – and thus react – in different ways to changes in water availability and pricing. The four farming systems classes were labeled according to the major sources of their income as (i) low family income, L, (ii) medium family income, M), (iii) high mixed family income, HM), (iv) high farm and family income farming system class, HFF. Water quality in the study area was determined by the geographical location of cropped land and showed no interdependency with membership of farming systems in any one of the four classes. Irrigation plots in the north Jordan Valley received fresh water from the Yarmouk River, while those in the middle and south Jordan Valley received water of lower quality, which was a mixture of Yarmouk River water and treated wastewater from the King Talal dam.

Family size was about 11 persons per family and not statistically different between the four classes. However, farming systems had significantly different family labor capacities, (highest in class HM) and dependency ratios, i.e. the number of dependants per family member in an active age, which was highest in class L. Another important result from the analysis was that the amount of cultivated area was more important than ownership of land in achieving economic success. The contribution of farm income to family income decreased as the share of off-farm activities increased. The medium income class M had the highest proportion of off-farm income. This was followed by the high mixed income class (HM). The low income class L relied almost totally on farming. Most farmers depended on outside ownership for more than one of the basic resources, i.e. water, land, capital and labor, limiting their freedom in decision-making.

The majority of the farmers interviewed receive irrigation water from the Jordan Valley Authority (JVA), but 81% have at least additional access to privately owned artesian wells. This extra access was particularly evident in families from class HM. Other significant differences concerned investments and credits. Farming systems from class HM had the highest investments in all sectors of agriculture, but were able to cover this mostly with their own capital. Farming systems from class HFF took the highest credits, but, in contrast to families from classes L and M, they addressed their credit demands to input suppliers rather than to the formal credit sector.

The model-based prognoses for the representative farming systems showed that changes in water availability or prices would significantly alter the economic success of families and their cropping patterns. Decreasing water availability in the range of 15-30%, which corresponds to a situation where freshwater is diverted from agriculture for other purposes and replacement by recycled water is no option, would, in particular, endanger the survival of farming systems at the lower end of the current scale of family incomes (class L). A subsequent reduction in agricultural production would affect, in the first place, the cultivation of tomatoes and stringbeans in all farming systems classes. All farming systems would benefit from increasing water availability. This corresponds to the impact from increasing use of recycled water for irrigation purposes, whereby the high income classes would benefit the most. The positive impacts on agricultural production would again occur first in tomato and bean production, but also for onion and egg-plant.

Increasing water prices, i.e. a situation where, for example, a percentage of water purification costs are charged to the farmer, would lead to tendencies similar to those caused by a reduction in irrigation water. The resulting reduction of water demand would, however, be strongest in the low-income farming systems. This would probably mean closing down part of these farming systems, with the associated consequence of the affected families emigrating to other, most likely urban, areas.

4 Conclusions

Water is scarce in the irrigation area of the Jordan Valley Authority (JVA). The centralized management of the predominant part of available water by the JVA stands against a diverse range of individual farming systems. Results of the study indicate four major classes of farming systems, which have different initial situations and will be affected – and thus react – in different ways to changes in water availability and pricing. Further, spatial distinction of the location of farming systems from the four classes is required, to anticipate different developments in water availability in different parts of the study region.

Increasing prices for irrigation water, as well as decreasing water availability, would have significant impacts on the obtainable farm income, which endanger at least the survival of farming systems at the lower end of the family income scale. The model-based prognoses for representative farming systems allowed also for the quantification of related changes in cropping patterns, thus providing a platform for further research into secondary effects on Jordanian markets for agricultural inputs and products. In combination, research at these different levels would enable conclusive decision making on future water supplies in agriculture.

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Concluding Sessions

Concluding Sessions

Session 1: Summarizing workshop discussions and research challenges and gaps

Chairperson: Liqa Raschid-Sally, IWMI, West Africa, Accra, Ghana

This session summarized the discussions and outcomes of the 4-day interactions among participants and resource persons. The following key topics, emerging from the different stimulating sessions, were presented:

- The upstream-downstream concept and reverse water chain approach
- Upstream interventions that affect downstream water users
- Outcomes that downstream users want to achieve by influencing upstream intervention decisions
- Holistic planning for resource recovery (water/nutrients) with integrated solutions that address the benefits but also the health risks involved
- The crucial role of multiple stakeholders when using wastewater in agricultural production systems.

Participants identified research challenges and gaps via an interactive exercise where they were divided into two groups: a multidisciplinary group of experts; and a group of downstream stakeholders (farmers, households, and other users). The groups were given the task of designing a fast growing city with a current population of 100,000 inhabitants, which is located in a region of 400 mm annual rainfall, and may face water scarcity. The city has currently received many applications from industry to set up factories.

***Group 1*:** This group was asked to design the new city for optimal use of water and other resources with benefits for agriculture, taking into account key considerations and constraints. Initial discussion focused on different development elements in the design plan. The team decided that the city was located upon a river. The city center is located at the confluence of two streams feeding the river, and is surrounded by residential and industrial areas. The team presented a draft land use plan to define the different activities taking place in different areas (Figure 1). Pollutants from the industrial zone included those going into a combined sewer system, from which effluent would be sent to a wastewater treatment plant. The design of the centralized treatment system would take care of this industrial pollution.

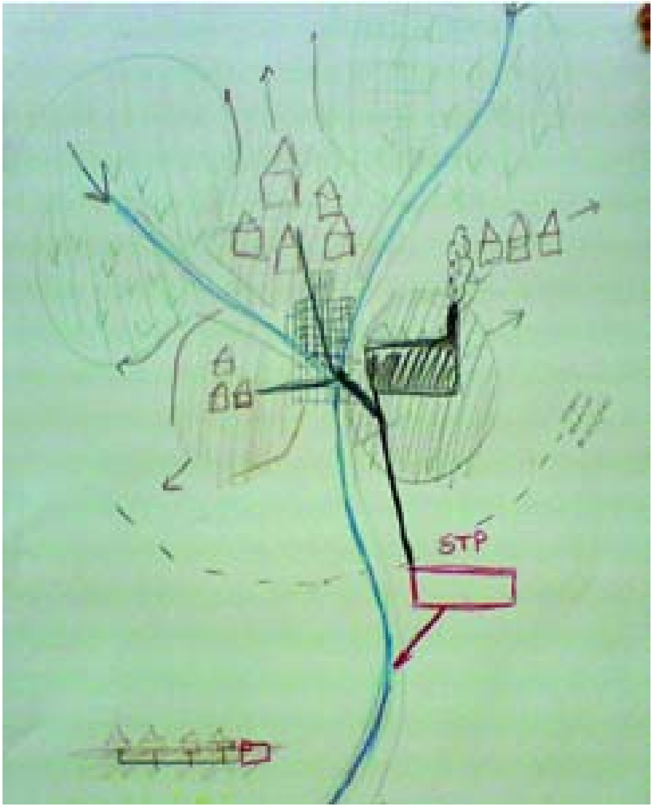

Fig. 1 Anticipated design as conceived by Group 1 (multidisciplinary group of experts) for a rapidly growing city for optimal use of water resources with benefits for agriculture. Considered to be upon a river, the city center is located at the confluence of two streams feeding the river.

The group envisaged two different agricultural systems: upstream freshwater-based agriculture, and downstream wastewater-fed agriculture. Upstream, the quality of water is good. Downstream, water is polluted from wastewater effluent. Crop quality from upstream agriculture is better, but yield per unit area is lower than in the downstream area.

The team considered preserving agricultural land zoning in order to avoid encroachment of residential and industrial establishments over agricultural land. However, land tenure and market pressure may over-ride this aim. So, instead, the team decided to confine industrial expansion in a landward direction in order to avoid continued pollution of the river. The downstream population could be affected by pollution but the 'polluter pays' principal could be implemented to address this concern.

Group 2: This group was asked to design the same city to suit the needs of downstream communities along with benefits in terms of resource use. The group addressed farmers' needs – a sufficient quantity of good quality water, no pollutants from industry, a good village environment, and good quality produce for higher incomes. These considerations prompted the group to list several demands:

- Stakeholder involvement throughout the planning process
- Facilitation of marketing for better production
- Improved municipal-level planning
- Treatment of wastewater
- Legislation and control over water quality and wastewater management
- Regular water quality assessment
- Crops without restrictions
- Clean good-quality drinking water
- Solid waste management by municipalities.

At the system level, the following considerations were proposed:

- A treatment plant located outside the city
- Separation of industrial wastewater from domestic wastewater
- Treated wastewater disposed of in the canal and used for irrigation
- No industrial setup in the agricultural zone
- Installation of wastewater treatment plant as a prerequisite for estabishing industry
- Treated industrial wastewater used for forest and tree species
- Decentralized wastewater treatment for rural areas
- Treated wastewater with no industrial waste used with no restrictions for agriculture, leading to safe products, less disease, and a better environment.

Session 2: Participants' perspectives – the way forward

Resource Person: Manzoor Qadir, ICARDA-IWMI Joint Appointment on Marginal-quality Water Resources; ICARDA, Aleppo, Syria; and IWMI, Colombo, Sri Lanka

This session revealed feedback from developing-country participants, as a way to prioritize research and practice addressing different aspects of wastewater – generation, collection, treatment, use, implications, and overall management. The participants were asked to suggest up to three topics they considered important in this regard. A total of 33 topics/aspects were suggested by the participants and later grouped into 14 categories, listed below.

1 Upstream-downstream challenges for wastewater management
2 Wastewater use and its impacts on livelihoods and health
3 Wastewater use and its impacts at a national level
4 Wastewater management vis-à-vis stakeholder involvement at different levels
5 Bridging the gap between research and farmers' practices involving wastewater in low-income countries
6 Developing networks and organizing workshops for sharing research experiences and knowledge on wastewater use
7 Developing holistic approaches for wastewater management
8 Capacity development for water quality monitoring and wastewater management
9 Mechanisms and policy options for separation of industrial wastewater from domestic wastewater and treatment of industrial wastewater
10 Design options for decentralized wastewater treatment in developing countries
11 Exploiting the possibility of organic farming with treated wastewater
12 Exploiting the role of plant species (phytoremediation) as a potential option for wastewater management and environment clean-up
13 Evaluation of inorganic and organic pollutants in wastewater
14 Evaluation of recent WHO guidelines for their applicability on wastewater use under different environments

The participants prioritized the above topics that they considered important for research and practice relating to wastewater. Receiving five scores (~15% of the responses) each, the two most important topics suggested were: bridging the gap between research and farmers' practices in low-income countries; and developing holistic approaches for wastewater management. These two topics were followed by another priority set of three topics with three scores (~9% of the responses) each. These included: upstream-downstream challenges for wastewater management; wastewater use and its impacts on livelihoods and health; and stakeholder involvement throughout the planning and operational processes of wastewater management (Figure 2).

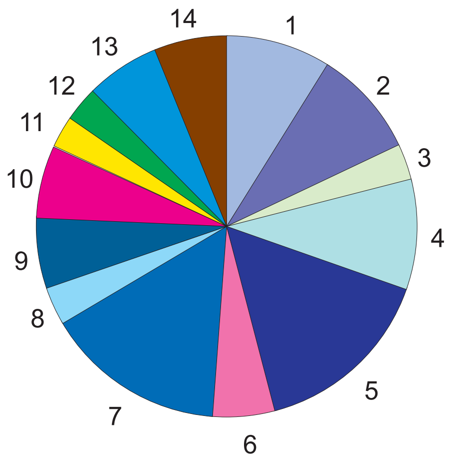

Fig. 2 *Response of workshop participants in terms of prioritizing the research and practice addressing different aspects of wastewater.*
1 = upstream-downstream challenges, 2 = livelihood and health implications, 3 = national level impacts, 4 = stakeholder involvement at all levels, 5 = bridging research-farmers' practices gap, 6 = networks and workshops for knowledge sharing, 7 = developing holistic approaches, 8 = capacity development for water quality monitoring, 9 = separation of industrial wastewater from domestic wastewater, 10 = decentralized wastewater treatment in developing countries, 11 = organic farming with treated wastewater, 12 = phytoremediation, 13 = addressing inorganic and organic pollutants, 14 = evaluation of recent WHO guidelines

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