Wastewater Use in Irrigated Agriculture

Confronting the Livelihood and Environmental Realities

Edited by C.A. Scott, N.I. Faruqui and L. Raschid-Sally

IWMI International Water Management Institute

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Foreword

Growing water scarcity threatens economic development, sustainable human livelihoods, environmental quality, and a host of other societal goals in countries and regions around the world. Urban population growth, particularly in developing countries, places immense pressure on water and land resources; it also results in the release of growing volumes of wastewater – most of it untreated. Wastewater is increasingly being used for irrigation in urban and peri-urban agriculture, and even in distant rural areas downstream of the very large cities. It drives significant economic activity, supports countless livelihoods particularly those of poor farmers, and very substantially changes the hydrology and water quality of natural water bodies. There are of course rather serious drawbacks for human health and the environment that result from using wastewater without adequate safeguards. The challenge is to identify practical, affordable safeguards that do not threaten the substantial livelihoods dependent on wastewater, or diminish the important role this resource plays in achieving household food security and supplying low-cost produce to growing cities.

The Millennium Development Goals aim to halve, by 2015, the number of people without access to water supplies or safe and affordable sanitation. Sustainable and safe wastewater use can support the achievement of these goals by preserving valuable fresh water for drinking. Furthermore, sanitation goals have always been difficult to achieve, as other priorities always seem to attract scarce resources. To ensure the efficient use of funds, the goal of improved sanitation should be pursued with the objective of wastewater use in mind, as the type of technology selected can either help or hinder the goal of reuse. Using wastewater for agriculture, i.e. valuing both the water resource and the nutrients for a new productive use, changes the thinking from having to deal with a costly nuisance to trying to harvest a potentially valuable resource.

The present volume addresses these issues head-on through a series of thematic chapters aiming to better understand wastewater use in agriculture in developing countries and detailed case study documentation of what works and what does not. The book is part of ongoing collaboration between the International Water Management Institute (IWMI) and the International Development Research Centre (IDRC). Both our institutions are committed to the sustainable use of natural resources in developing countries, and while we may approach the subject of wastewater from diverse perspectives, we agree that wastewater is a resource of growing global importance and that sustainably managed, it can greatly enhance livelihoods and

improve environmental quality. This central tenet is recognized in the *Hyderabad Declaration on Wastewater Use in Agriculture* (Appendix 1, this volume), an important outcome of the joint IWMI-IDRC workshop held 11–14 November 2002 in Hyderabad, India.

The editors and contributing authors represent a wide spectrum of experience and perspectives on wastewater use in agriculture, and collectively form a growing 'community of practice' that will generate, exchange and broker knowledge. The volume should serve to change thinking on the part of decision makers in such international bodies as the World Health Organization, national and state governments (some of whom were present at the November 2002 workshop in Hyderabad), researchers and practitioners. Both IWMI and IDRC see this as an important boost to promoting safe and sustainable use of wastewater.

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1 Wastewater Use in Irrigated Agriculture: Management Challenges in Developing Countries

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Abstract

Cities in developing countries are experiencing unparalleled growth and rapidly increasing water supply and sanitation coverage that will continue to release growing volumes of wastewater. In many developing countries, untreated or partially treated wastewater is used to irrigate the cities' own food, fodder, and green spaces. Farmers have been using untreated wastewater for centuries, but greater numbers now depend on it for their livelihoods and this demand has ushered in a range of new wastewater use practices. The diversity of conditions is perhaps matched only by the complexity of managing the risks to human health and the environment that are posed by this practice. An integrated stepwise management approach is called for, one that is pragmatic in the short- and medium terms, and that recognises the fundamental economic niche and users' perceptions of the comparative advantages of wastewater irrigation that drive its expansion in urban and peri-urban areas. Comprehensive management approaches in the longer term will need to encompass treatment, regulation, farmer user groups, forward market linkages that ensure food and consumer safety, and effective public awareness campaigns. In order to propose realistic, effective, and sustainable management approaches, it is crucial to understand the context-specific tradeoffs between the health of producers and consumers of wastewater-irrigated produce as well as the quality of soils and water, on the one hand, and wastewater irrigation benefits, farmers' perceptions, and institutional arrangements on the other. This introductory chapter to the current volume on wastewater use in agriculture highlights a series of tradeoffs associated with continued use of untreated wastewater in agriculture. Empirical results from the case studies presented in the volume shed light on devising workable solutions.

Rapid Expansion of Wastewater Irrigation in the Coming Decades

The use of urban wastewater in agriculture is a centuries-old practice that is receiving renewed attention with the increasing scarcity of freshwater resources in many arid and semi-arid regions. Driven by rapid urbanisation and growing wastewater volumes, wastewater is widely used as a low-cost alternative to conventional irrigation water; it supports livelihoods and generates considerable value in urban and peri-urban agriculture despite the health and environmental risks associated

 Wastewater Use in Irrigated Agriculture (eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

with this practice. Though pervasive, this practice is largely unregulated in low-income countries, and the costs and benefits are poorly understood.

This volume critically reviews worldwide experience in the use of wastewater for agriculture through a series of chapters defining and elaborating on the issues at the centre of the debate around wastewater use in agriculture. Particular emphasis is placed on untreated wastewater use through field-based case studies from Asia, Africa, the Middle East, and Latin America, which address the environmental and health impacts and risks of the practice. These chapters consider multiple aspects including the economic, social, health, agronomic, environmental, institutional, and policy dimensions and the research needs related to this growing practice. The editors conclude with a prognosis of future challenges and realities of wastewater use in agriculture.

Cities throughout the developing world are growing at unprecedented rates, yet there are no reliable data on the sewage volumes they generate or any comprehensive assessments of the fate or use of urban wastewater. However, because sewage collection and its disposal as wastewater are increasing in developing-country cities as a function of the growth in urban water supply, water supply coverage is a reasonable proxy for projecting increases in wastewater volumes. Increases in urban water supply depend on myriad factors and will likely be unable to keep pace with urban population growth, implying falling per capita water supply rates. In spite of the fact that trends show that rates of urbanisation are likely to slow down in developed countries, in many countries of the developing world urbanisation will continue rapidly. As a result, wastewater flows will increase in the future. In developing countries where investments in water supply far outpace those in sanitation and waste management, suffice it to say that treatment and disposal of wastewater are inadequate or non-existent and that raw sewage – full-strength or diluted – is used and even competed for in order to irrigate food, fodder, ornamental and other crops.

We suggest that raw wastewater use in agriculture is presently increasing at close to the rate of urban growth in developing countries subject to urban and peri-urban land being available. Consider the demographics that will drive expansion in the volumes of wastewater generated. It is projected that 88% of the one billion growth in global population by 2015 will take place in cities, essentially all of it in developing countries (UNDP, 1998). Developed countries' populations are expected to decline 6% by 2050, while the global rural population should plateau at approximately 3.2 billion. The result is that after 2015, all worldwide growth in population will take place in developing-country cities. Cities are home to political and economic power and will continue to ensure that their water supply needs are met on a priority basis subject to physical and economic scarcity constraints. The Millennium Development Goals call for halving the proportion of people without access to improved sanitation or water by 2015. As a result, an additional 1.6 billion people will require access to a water supply – 1.018 billion in urban areas and 581 million in rural areas (WHO and UNICEF, 2000).

Water supply ensures wastewater because the depleted fraction of domestic and residential water use is typically only 15–25% with the remainder returning as wastewater. Although the numbers of urban dwellers in developing countries that continue to rely on septic tanks, cesspits, etc. is unexpectedly high, growing numbers are connected to sewers that deliver wastewater – largely untreated – to downstream areas. Very often too in spite of onsite sanitation, substantial volumes of domestic wastewater including toilet wastes find their way into surface water networks within cities. Table 1.1 shows by region the percentages of sewerage coverage and the wastewater actually treated.

This volume covers wastewater management examples from Africa, the Middle East, Latin America, and Asia. Although the challenges are significant in all these regions, in terms of overall magnitude (volumes of wastewater, numbers of people affected, and land irrigated) Asia represents the largest challenge. Despite the relatively high sewerage and treatment figures reported for Asia in Table 1.1, most of the global growth in urban water supply will take place in this region as seen in Fig. 1.1. The total numbers of people in Asian cities will generate such large volumes of wastewater that

Table 1.1. Sewerage coverage and wastewater treatment by world region.

Region	Population (%) in large cities that is sewered	Sewered wastewater (%) that is treated to secondary level
Africa	18	0
Asia[a]	45	35
Latin America/ Caribbean (LAC)	35	14
Oceania	15	Not reported
Northern America	96	90
Europe	92	66

[a] The *Global Water Supply and Sanitation Assessment 2000 Report* figures for Asia include Japan, South Korea, Taiwan, and other developed countries (WHO and UNICEF, 2000).

downstream agriculture with highly polluted wastewater is well nigh unavoidable. In India for example, the major bulk of population growth is expected to occur in 40–45 cities each with population greater than 100,000, not just in the mega cities (Amitabh Kundu, urban demographer, personal communication). Based on Central Pollution Control Board data for 2001, the Infrastructure Development Finance Corporation estimates that 73% of urban wastewater in India is untreated, requiring an investment in treatment capacity of the order of US$65 billion or ten times greater than what the Government of India proposes to spend (Kumar, 2003). China is also experiencing rampant urban growth. In both countries, sewerage coverage and wastewater treatment lag behind water supply, which in turn lags behind population growth.

These demographic processes coupled with increasing purchasing power will create unprecedented demand in urban markets for vegetables, milk, ornamental plants, etc. that are readily – in fact, competitively – produced using the wastewater that urban consumers themselves generate. With water scarcity, land

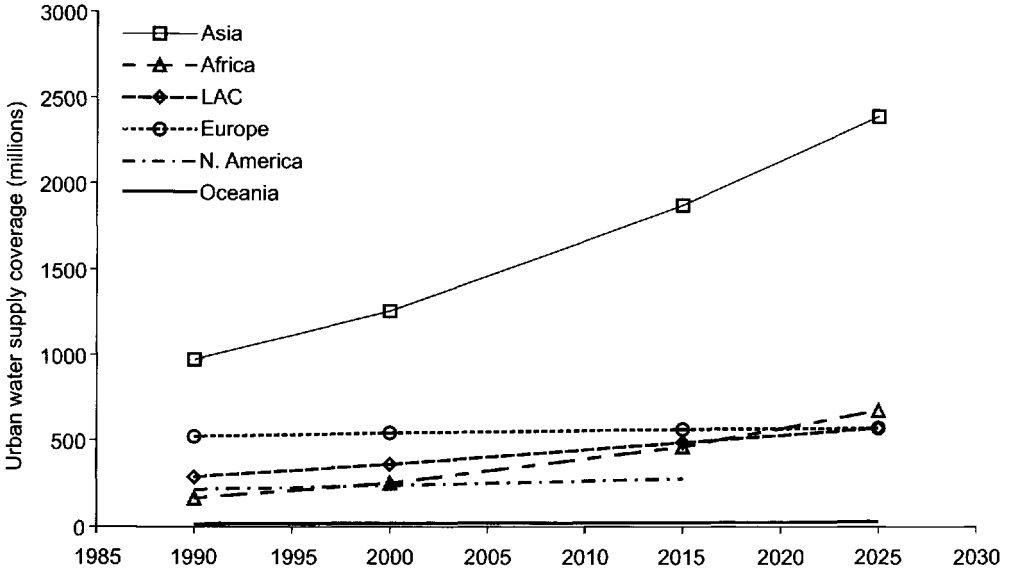

Fig. 1.1. Growth in urban water supply coverage by world region.

pressure, and little feasible budgetary alternative for effectively treating the growing wastewater volumes, the burgeoning of wastewater irrigation in developing country cities is already taking place.

Although it is impossible to devise effective management solutions from such global wastewater trends, our purpose at this juncture is to flag the immensity of the challenges of wastewater management in the urban and peri-urban fringe, where irrigation of a range of produce for urban markets is the most common use of wastewater. The challenges of wastewater management in the urban to peri-urban corridors will unavoidably grow more complex.

Both the pragmatists who see the difficulty in applying bans on wastewater irrigation and the detractors of wastewater use in agriculture find ample cause to bolster their positions. Numerous case studies on the dynamics of urban agriculture show that wastewater irrigation supports countless livelihoods of both marginal and better-established, or even commercial farmers and the labourers they employ, all of whom occupy production and marketing niches. These social and economic processes driving wastewater irrigation may often be overlooked from the regulatory perspective of urban, public health or environmental authorities who view the protection of public health and environmental quality as their primary objectives, despite the fact that regulators may be aware that urban farming using wastewater is a prevalent phenomenon. Furthermore, in many instances regulations are not applied with adequate rigour, entailing that purely regulatory approaches to manage wastewater irrigation tradeoffs are inevitably ineffective. For example, Accra, Ghana has passed regulations on the use of urban wastewater; but farmers largely ignore them and authorities are incapable of enforcement (Keraita and Drechsel, Chapter 9, this volume).

In water-scarce and even humid regions, farmers prize the water and nutrient value and supply reliability of the wastewater stream. And under the most common scenario in water-scare countries of a city expanding more rapidly than its water supply, sewage may water what little green space remains.

Irrigation with untreated wastewater can represent a major threat to public health (of both humans, and livestock), food safety, and environmental quality. The microbial quality of wastewater is usually measured by the concentration of the two primary sources of water-borne infection – faecal coliforms and nematode eggs. A range of viruses and protozoa pose additional health risks. Wastewater has been implicated as an important source of health risk for chronic, low-grade gastrointestinal disease as well as outbreaks of more acute diseases including cholera (e.g. Jerusalem and Dakar) and typhoid (Santiago). Disease agents are found in wastewater that drains from planned residential areas and slums alike. The health of the urban poor is particularly linked to inadequate management of wastewater. Chronic diarrhoeal and gastrointestinal diseases, which disproportionately affect urban slum dwellers who have inadequate sewerage and sanitation facilities, are clearly major negative outcomes of exposure to wastewater. A primary exposure route for the urban population in general is the consumption of raw vegetables that have been irrigated with wastewater (Fattal *et al.*, Chapter 5, this volume). Additional exposure routes for the urban poor, who are often migrants with little access to health services, include direct contact with solid waste and wastewater, as for instance through riverside open defecation grounds.

Additionally wastewater irrigation of vegetables and fodder may serve as the transmission route for heavy metals in the human food chain. Particularly in South Asia, where per capita milk consumption is the highest in the developing world and growing rapidly (Delgado *et al.*, 1999), wastewater is increasingly used to irrigate fodder that supplies an urban and peri-urban livestock-based production chain. Evidence of heavy metal transmission through milk is presented by Swarup *et al.* (1997). In the absence of chilling, storage and transport facilities, milk must be produced as close to market as possible; it represents an important urban and peri-urban agricultural product. Further, fodder cultivation is particularly well matched to wastewater; it requires continual irrigation application and is generally tolerant of the high salinity levels characteristic of urban wastewater.

Finally, the environmental quality of soils,

groundwater and surface water, and to a lesser degree, stream channel biota and ecological conditions as indicated by the biodiversity of the wastewater-contaminated river or other receiving water body are often the second-order casualties if wastewater is disposed indiscriminately.

Cities in both arid and humid regions are witnessing unprecedented expansion of urban and peri-urban agriculture using poor-quality water. For example, in Bolivia, indirect use of wastewater takes place in almost all rural and peri-urban areas downstream of the urban centres (Huibers *et al.*, Chapter 12, this volume). Additionally, although wastewater irrigation has been thought to be limited to large cities, in regions such as Gujarat, India, it is common even downstream of small towns and villages (Bhamoriya, Chapter 11, this volume). As seen in the cases of Vietnam (Raschid-Sally *et al.*, Chapter 7, this volume), Jordan (McCornick *et al.*, Chapter 14, this volume), Senegal (Faruqui *et al.*, Chapter 10, this volume), or Bolivia (Huibers *et al.*, Chapter 12, this volume), the implications for public health and the environment are equally serious whether wastewater is intentionally used for irrigation or whether it is simply mixed with freshwater that is used for irrigation.

In sum, wastewater is a resource of growing global importance and its use in agriculture must be carefully managed in order to preserve the substantial benefits while minimising the serious risks. This reality was recognised and its implications deliberated in the *Hyderabad Declaration on Wastewater Use in Agriculture* (Appendix 1, this volume), one of the outcomes of a workshop held 11–14 November 2002 in Hyderabad, India and sponsored by the International Water Management Institute (IWMI, based in Colombo, Sri Lanka) and the International Development Research Centre (IDRC, based in Ottawa, Canada). The other outcome is this volume – most of the chapters were drawn from the workshop, which had the following objectives:

- To critically review experience worldwide in the use of wastewater for agriculture
- To present lessons learned from specific field-based case studies, including the environmental and health impacts and risks of wastewater use in agriculture
- To refine a methodology developed and applied by IWMI for selected countries that seeks to assess the global extent of wastewater use in agriculture
- To evaluate the institutional arrangements, constraints, and policy implications for sustained livelihoods based on wastewater use in agriculture
- To build a wastewater 'community of practice' integrating a variety of research, implementation and policy institutions and partners
- To offer some conclusions and recommendations for further research that help balance the need to protect public health and farmers' incomes.

This introductory chapter sets the stage for the chapters that follow in this book. The initial chapters address key thematic issues for wastewater management: a wastewater use typology, an overview of a wastewater-based sustainable livelihoods framework, discussion of public health guidelines, and assessment of the cost-effectiveness of treatment required to meet guidelines. There follow a series of case studies detailing wastewater use practices around the world, focusing on the complex set of challenges and identifying potential solutions. The emerging view is that a realistic approach requires that tradeoffs are considered in both the short and long terms. Several factors drive wastewater irrigation: the lack of equally remunerative livelihood alternatives, the continued expansion of the wastewater resource base, and the ineffectiveness of regulatory control approaches that have characterised most attempts at management. The experiences of countries that are in the process or have completed the conversion from untreated to regulated, treated reuse can serve as important lessons. The cases of Tunisia, Jordan and Mexico are presented in this volume.

Treated wastewater currently represents approximately 5% of Tunisia's total available water; this is planned to increase to 11% by 2030 (Shetty, Chapter 15, this volume). Salinity management remains a major objective of the Tunisian wastewater use programme. In Jordan, wastewater represents 10% of the current total water supply (McCornick *et al.*, Chapter 14, this volume). Groundwater recharge is one of the explicit uses of

wastewater in Jordan, but not for aquifers that are used for drinking water supply. The previous (waste-) water quality standards required some revision in order to accommodate Jordan's plans to reuse water, particularly for sprinkler irrigation, which was prohibited for wastewater. In order to meet strict export phytosanitary controls, the irrigation of vegetables eaten raw with reclaimed water, no matter how well treated, remains prohibited in Jordan. In Mexico, implementation of wastewater treatment (but not necessarily its use) has been mandated by federal environmental quality regulations (Silva-Ochoa and Scott, Chapter 13, this volume). While wastewater use in agriculture is a common practice, particularly in Mexico's vast arid and semi-arid areas, it is mostly practised informally with the result that planned treatment for use in agriculture is not common. Instead, municipal water boards that bear the cost of treatment prefer to seek paying customers for treated wastewater, particularly golf courses, urban green spaces, etc.

Estimating the Magnitude of Wastewater Use in Irrigated Agriculture

Just how prevalent wastewater irrigation is today is a matter of conjecture; no sound, verifiable data exist. Earlier approximations by Scott (in Future Harvest, 2001, that were intended to stir the debate), based on figures for sewage generated, treatment capacity installed, assumptions of the proportion of peri-urban areas without wastewater demand for agriculture (e.g. coastal cities, etc.), freshwater mixing ratio, and annual irrigation depths, placed the area at 20 million ha of irrigation using raw or partially diluted wastewater. Since the release of this first-cut estimate, the reactions have been multiple that:

1. The 20 million ha figure is an overestimation of 'raw sewage irrigation' given that it includes areas irrigated with partially diluted wastewater
2. Wastewater irrigation is not important enough a phenomenon to warrant resources for research and management
3. The magnitude of the problem is significantly greater than that implied by the 20 million ha estimate
4. Isolated case studies barely scratch the surface and indeed irrigation using wastewater or seriously polluted water is pervasive and represents a major concern.

Clearly there is a need to establish and apply a verifiable method for determining the prevalence of wastewater irrigation. As an important first step in this direction, van der Hoek (Chapter 2, this volume) presents a typology. Raschid-Sally *et al.* (Chapter 7, this volume) and Cornish and Kielen (Chapter 6, this volume) present assessments at the country level with estimates of 9,000 ha for Vietnam and 11,900 ha for Ghana. Ensink *et al.* (2004) estimate that 32,500 ha are irrigated with wastewater in Pakistan. These results are based on a typological definition of undiluted wastewater, i.e. 'end-of-pipe' sewage irrigation, which does not account for irrigation using water polluted with wastewater, that poses many of the same risks and management challenges. Van der Hoek's typology includes marginal quality water, i.e. polluted surface water; however, country estimates have tended to focus on undiluted wastewater irrigation, suggesting that 20 million ha is an overestimation of the global extent of the practice. It is important to recognise, however, that improved estimates of global wastewater irrigation would need to account for a number of countries with rapidly growing cities and large national irrigation sectors including particularly China, Egypt, India, Indonesia, Iran, Mexico, and Pakistan.

This does not detract from the importance of wastewater irrigation or the difficulty of the management challenges in other countries or regions. Further, getting a precise fix on the global extent of wastewater irrigation should not deflect attention or resources from the far more substantive management issues that are invariably context-specific as demonstrated in the case studies presented in this volume.

Multiple complementary factors drive the increased use of wastewater in agriculture. Water scarcity, reliability of wastewater supply, lack of alternative water sources, livelihood and economic dependence, proximity to markets, and nutrient value all play an important role. Water scarcity and reliability of wastewater supply are crucial. The case studies in this volume of Dakar in Senegal,

Cochabamba in Bolivia, and Vadodara in India all demonstrate this. That farmers have few alternative water sources may be true where wastewater is mixed with freshwater; however, in water-scarce regions, wastewater is invariably the only source. Interestingly in some cases, as in Pakistan where canal irrigation water is available, although with reliability and supply constraints particularly in the tail-end reaches of the irrigation systems, many farmers convert to wastewater by choice. Livelihood dependence for poor farmers remains the single most important socioeconomic driver of the practice, yet it is misleading to assume that all wastewater farmers are poor (Buechler, Chapter 3, this volume). Indeed, larger, commercial-scale farmers have made inroads and may compete with small-scale farmers for wastewater as well as for markets. Additionally, because of the market orientation of much wastewater agriculture in urban and peri-urban contexts, it absorbs significant labour, much of it female (Keraita and Drechsel, Chapter 9, this volume, and Faruqui *et al.*, Chapter 10, this volume). Finally, while most farmers acknowledge the nutrient value of wastewater this appears to be a secondary driver, i.e. the scarcity or poor quality (usually salinity) of alternative sources is generally more important.

Wastewater irrigation will remain consigned to informal practice and as a result management approaches must start at the informal or semi-formal level. Two important characteristics of wastewater irrigation in the case studies on Asian cities presented in this volume (Bhamoriya and Buechler from India; Ensink *et al.* from Pakistan) are semi-formal institutional arrangements and prominent, yet farmer-initiated, infrastructure for irrigation using untreated wastewater. Both suggest a degree of institutionalisation that is not evident in untreated wastewater use in other regions. While the use and livelihood dependence on wastewater in African cities is not entirely dissimilar, it is hypothesised that social relations and land tenure issues related to state or communal ownership of land may not result in the same formalisation of wastewater irrigation in urban and peri-urban agriculture as seen in Asian cities. By contrast, many countries in North Africa (Shetty, Chapter 15, this volume), the Middle East (McCornick *et al.*, Chapter 14, this volume), and Latin America (Silva-Ochoa and Scott, Chapter 13, this volume) have embarked on formal *treated* water reuse programmes. These provide important lessons, discussed in the conclusions, for the design of programmes to make the transition from informal to formal wastewater use.

Uni-dimensional management solutions for wastewater irrigation that employ exclusively technical (treatment) or regulatory (bans, crop restrictions, etc.) approaches have generally been inadequate. In isolation neither fully takes account of the multiple drivers of the process, nor the need for integrated management solutions. Realistic and effective management approaches rarely hold up technical or regulatory approaches as the complete solution, but instead seek to apply these in an integrated way. The more difficult question, particularly in the context of weak regulatory implementation, lies in the multiple – often competing – needs to secure livelihoods based on wastewater irrigation on the one hand, and public health and environmental protection imperatives on the other. Should the economic realities of a few override the need to protect broader societal goals? Clearly not, yet a more pragmatic approach is required than has been implemented in most developing country contexts. As discussed in the concluding chapter of this volume, we advocate a graduated approach to meeting targets [termed 'stepwise' in the *Hyderabad Declaration on Wastewater Use in Agriculture* (Appendix 1, this volume)], specifically that all aspects of the solution must be realistic. The concluding chapter elaborates the essential recommendations from this volume, i.e. 1. develop and apply appropriate guidelines for wastewater use, 2. treat wastewater and control pollution at source, 3. apply a range of non-treatment management options, and 4. conduct research to improve understanding of the practice as well as opportunities and constraints to adoption of these recommendations.

Guidelines for Health and Environmental Quality

The single most important rationale for more stringent control over wastewater use in agriculture is the risk posed to human health (of irrigators, consumers of produce, and the general public) and to the environment. Guidelines for wastewater use and standards for water quality matched to particular end uses have been developed and applied with varying degrees of success. Two sets of guidelines that aim to protect human health under conditions of planned reuse of treated wastewater – those set out by the World Health Organization (see Carr *et al.*, Chapter 4, this volume) and the United States Environmental Protection Agency (USEPA) – have raised considerable controversy in particular with respect to their feasibility and applicability in different developing country contexts. Fattal *et al.* (Chapter 5, this volume) estimate that the cost of treating raw sewage used for direct irrigation to meet the current WHO microbial guideline of 10^3 faecal coliforms/100 ml is approximately US$125 per case of infection (of hepatitis, rotavirus, cholera, or typhoid) prevented. By comparison, the incremental cost of further treating wastewater from the WHO to the USEPA microbial guideline is estimated to be US$450,000 per case of infection prevented.

It is not our purpose here to join the guidelines debate, except to insist that cost-effective risk mitigation be the primary goal of any programme that includes guidelines for wastewater use in agriculture. Developing and applying pragmatic guidelines based on *managed risk* or *acceptable risk* instead of *'no risk'* criteria must be the approach adopted. As detailed by Carr *et al.* (Chapter 4, this volume), the Stockholm Framework encourages flexibility in the adoption of wastewater use guidelines to facilitate progressive implementation of guidelines and to account for local conditions, particularly other risk factors that may be more acute than microbial diseases linked to wastewater. Additionally, Carr *et al.* identify a number of beneficial outcomes of wastewater use that tend to be overlooked in the guidelines debate. A key factor that needs to be integrated in any future approach is the livelihoods dimension of such unplanned use and the associated benefits (Buechler, Chapter 3, this volume; Drechsel *et al.*, 2002).

There are two primary constraints to the adoption of any set of guidelines: firstly infrastructure, operation and maintenance, and the associated investment and recurring costs that are required to handle or treat wastewater to the quality levels stipulated in the guidelines, and secondly regulatory enforcement to ensure compliance with required practice on the part of water authorities, those discharging wastewater, and those handling and using wastewater. Invariably the infrastructure issue is seen as the principal challenge, so that much of the debate is centred on wastewater treatment plants, their design, cost of operation, maintenance, etc. The assumption appears to be that with adequate technical control, the need to limit wastewater discharge and subsequent use is sufficiently minimised. This places ultimate responsibility for guidelines compliance on urban development authorities who control the finance of wastewater infrastructure and on wastewater treatment plant operators. Yet in the case of planned reuse there are larger institutional issues that permit (or impede) the implementation of wastewater use programmes, of which guidelines may be an important component. As seen in the Tunisian and Jordanian cases, the other 'software' components of such programmes including inter-agency coordination, public awareness campaigns, and emergency response (to disease outbreaks, etc.) are critical to risk mitigation.

In developing-country contexts, however, use of wastewater is an unplanned activity, and authorities tend to view the responsibility of regulating its use as a burden. In the absence of resources for treatment infrastructure and regulatory control, the guidelines proposed by the WHO, while relevant in a planned reuse context, are relegated to the status of targets (usually unachievable) instead of norms for practice. The distinction between norms and targets is an important one. Norms require compliance with a minimum acceptable level of practice, e.g. wastewater discharge for

unrestricted irrigation must have less than 10^3 faecal coliforms per 100 ml. Targets are feasible but invariably unachieved levels, e.g. wastewater treatment plant X discharges effluent with 10^4 faecal coliforms/100 ml, almost meeting the 10^3 target.

Short-term and Long-term Scenarios and Tradeoffs

Based on projected increases in urban water supply coupled with improved sewage collection resulting from sanitation programmes, the volumes of wastewater released from developing-country cities will certainly increase in the short (next 5 years) and long (next 25 years) terms. At least three factors relevant to the subject of this volume make long-term future projections of the global extent of wastewater irrigation problematic:

1. The poor reliability of water supply goals as a proxy for increases in the volumes of wastewater generated over the long term
2. Uncertainty in the degree and effectiveness of treatment that is implemented and sustained for those volumes of sewage that are collected
3. Changing societal demands for health and environmental protection that necessarily must be the driving force behind compliance and enforcement of wastewater irrigation guidelines and related regulatory frameworks.

In the short term, wastewater use will continue to grow and the immediate priority challenges are posed by the need to mitigate both chronic and acute risks while simultaneously addressing medium- and long-term constraints to integrated wastewater management. A priority short-term objective is to control wastewater exposure (through crop selection to minimise exposure of both consumers and producers, providing extension support for affordable but safer irrigation practices including piped distribution, field application using broad furrows that minimise crop and irrigators' exposure, protective equipment supported by public awareness, etc.). Second order, but potentially effective measures include therapeutic medical care for irrigators, e.g. anti-helminthic drugs, and provision of safe water in markets to protect consumers of vegetables eaten raw by ensuring that market produce is not washed or 'freshened' using wastewater.

In the medium term (10–15 years), wastewater treatment capacity is unlikely to keep pace even with water supply increases much less to make up the current gap between wastewater generated and collected and that actually treated. To find workable interim solutions, it is essential to table a dialogue among wastewater managers, urban authorities and existing irrigation users of untreated wastewater. For example, farmers should make known their interest in nutrients and organic matter. Urban authorities responsible for watering green spaces should share information with farmers to best allocate dry-season wastewater flows. Finally, downstream users should demonstrate to upstream producers of wastewater and to sanitation planning authorities that downstream agriculture is providing *de facto* treatment, but should insist on effective upstream contaminant source control and efforts to prevent particularly the more toxic constituents from entering the waste stream. Industrial sources of heavy metals, organics, and pharmaceutical waste need to be recovered in on-site or industrial park common effluent treatment plants before the liquid discharge is mixed with wastewater of primarily residential and commercial origin. End-of-pipe regulations for industries are much more enforceable from a purely logistical perspective – though perhaps more difficult institutionally when corruption and associated 'insider deals' are at play – than will be efforts to sewer, collect and treat wastewater from millions of dispersed urban residents in growing urban centres.

In the long term, wastewater treatment to at least primary level using settling basins or facultative lagoons must be the norm. Lowering the cost is essential if efforts to treat wastewater are to be effective. Although the costs of technology and even operation and maintenance of primary treatment are low, land value or the opportunity cost of urban or peri-urban land is often a formidable barrier to effective treatment in the long term. Urban authorities need to recognise the growth requirements now and set aside land for future treatment facilities in order to offset high future land

acquisition costs. They must also plan for integrated wastewater management that includes downstream beneficial uses of the wastewater.

At all stages, public awareness for farmers, authorities, and the public at large is essential, not just of the risks and benefits, but more importantly of several of the tradeoffs discussed here.

Conclusions

We have shown, based on our own experience and collaborations spanning multiple countries, continents, and contexts that irrigation using untreated wastewater is a prevalent phenomenon with multiple tradeoffs – between livelihoods and the need to protect health and the environment, between water demand under conditions of scarcity and the need for waste (water) disposal, and finally between informal practice led by farmers and formal institutional initiatives involving health, urban, water and agricultural authorities. A supreme degree of pragmatism and commitment is required under the realisation that effective solutions must be incremental and will take time to implement.

Planned reuse that seeks to maintain the benefits and minimise the risks will require an integrated approach. Key to the success of endeavours to make the transition to planned strategic reuse programmes are a coherent legal and institutional framework with formal mechanisms to coordinate the actions of multiple government authorities, sound application of the 'polluter pays' principle, conversion of farmers towards more appropriate practices for wastewater use, public awareness campaigns to establish social acceptability for reuse, and consistent government and civil society commitment over the long term with the realisation that there are no immediate solutions.

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2 A Framework for a Global Assessment of the Extent of Wastewater Irrigation: The Need for a Common Wastewater Typology

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Abstract

Policies on wastewater use have tended to focus on treatment before use and the implementation of strict regulations. But in many low-income developing countries untreated urban wastewater is used for irrigation. Clear policy guidelines on how to optimise the benefits and minimise the risks of this practice are lacking. A better estimate of the extent of wastewater irrigation is needed before the reality of its use can become an agenda item for policy and decision-makers. Secondary data and results of nationwide assessments should be aggregated to obtain a global estimate of use. For this, a common typology of wastewater use is needed that would need to address such aspects as: the direct use of urban wastewater versus the dilution of urban wastewater by natural surface water before use, the relative contributions of domestic wastewater, industrial effluent, and stormwater to urban wastewater, the extent to which the wastewater is treated, and the use of wastewater in formal irrigation schemes, or as informal irrigation by smallholders without external support or control. A typology of wastewater irrigation and a database structure for consolidation of results are proposed. It is intended that this should be developed into a framework for a global assessment of the extent and importance of wastewater irrigation.

Introduction

With the increasing scarcity of freshwater resources that are available to agriculture, the use of urban wastewater in agriculture will increase, especially in arid and semi-arid countries. The major challenge is to optimise the benefits of wastewater as a resource of both the water and the nutrients it contains, and to minimise the negative impacts of its use on human health. From the environmental aspect there are potentially positive and negative impacts that should be considered. International guidelines for use and quality standards of wastewater in agriculture exist (Mara and Cairncross, 1989). These standards can only be achieved if the wastewater is appropriately treated. Because of high treatment costs, most cities in low-income developing countries will not have wastewater treatment facilities in the foreseeable future. However, while the use of untreated wastewater has become a routine

 Wastewater Use in Irrigated Agriculture
(eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

practice in most developing-country cities, policies on its use have not taken this reality into consideration. Such policies range from active enforcement of legislation that totally prohibits the use of untreated wastewater, to turning a blind eye. Clearly, there is a need for better-informed decision-making.

To put wastewater use onto the international policy agenda there is a need to describe the importance of wastewater for integrated water resources management (IWRM), agricultural production, and to the livelihoods of poor urban, peri-urban, and rural populations. At present there are no clear estimates of the extent of irrigation with urban wastewater. Some people say it is an insignificant source of water for agriculture because the amounts of water diverted to cities and later disposed as wastewater are small in relation to the amount of water needed for agriculture in most developing countries. Others claim that worldwide, more than 20 million ha are irrigated with urban wastewater, and that wastewater has an important impact on agricultural productivity and livelihoods.

The International Water Management Institute (IWMI) proposes to lead a collaborative global assessment of the extent of wastewater use and has already initiated nationwide assessments in Vietnam and Pakistan. By linking up with other interested international and national institutions, a global database will be built that will be accessible in the public domain. This Global Assessment of the Extent of Wastewater Irrigation is linked to the Global Irrigated Area Mapping proposed by IWMI (Droogers, 2002), and the CGIAR's Comprehensive Assessment of Water Management in Agriculture (CGIAR, 2001a) which is a key component of the knowledge base for the Dialogue on Water, Food and Environment (CGIAR, 2001b).

This chapter aims to promote a common understanding of the characteristics of wastewater and its use in order to provide a framework for a global database of wastewater irrigation.

Definition of Wastewater

Definitions and concepts of wastewater are given in various reports and textbooks (Metcalf and Eddy, 1995; Westcot, 1997; Asano and Levine, 1998; Martijn and Huibers, 2001). In this report it is assumed that *urban wastewater* (Fig. 2.1) may be a combination of some or all of the following:

- Domestic effluent consisting of blackwater (excreta, urine and associated sludge) and greywater (kitchen and bathroom wastewater)

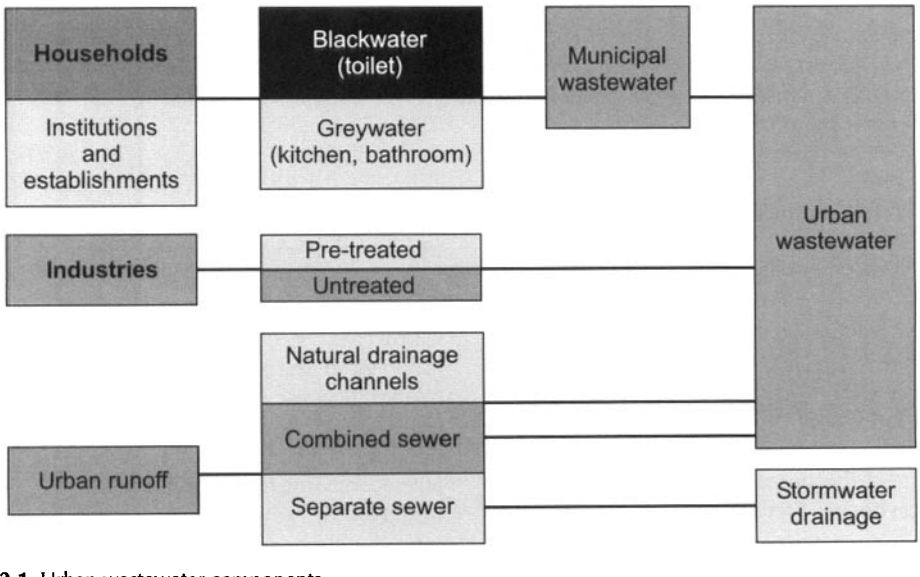

Fig. 2.1. Urban wastewater components.

- Water from commercial establishments and institutions, including hospitals
- Industrial effluent
- Stormwater and other urban runoff.

The actual proportion of each constituent within any given urban sewage load will vary due to spatial and temporal differences. For instance, monsoon climatic patterns will have a marked effect by diluting wastewater during heavy rains with the converse effect during hot and dry summers when there is more evaporation.

In irrigation sometimes the term **marginal quality water** is used. This refers to water whose quality might pose a threat to sustainable agriculture and/or human health, but which can be used safely for irrigation provided certain precautions are taken. It describes water that has been polluted as a consequence of mixing with wastewater or agricultural drainage (Cornish *et al.*, 1999). It can also include water with a high salt content. Such water can also be considered wastewater in the context of this chapter, but is not included in the Pakistan and Vietnam national assessments mentioned above.

The Need for a Typology of Wastewater Use

All kinds of variations in wastewater use are possible and it is to be expected that different uses will have different impacts on agricultural productivity, the environment, and human health. Appropriate policy decisions and technical interventions are likely to depend on the nature and characteristics of the wastewater and the way in which it is being used. A typology that can effectively capture these characteristics is required to ensure that those involved in this field are aware of the important differences that exist, and are able to identify where a given research finding, policy instrument, or technical intervention will and will not find relevant application. Cornish and Kielen (Chapter 6, this volume) propose a framework describing wastewater sources and use. The search for a single, all-embracing definition that says what is included and what is excluded from the notion of wastewater irrigation appears futile. Rather, a typology or a classification of the most common forms of wastewater use in irrigation must be developed. It is important that such a typology can be readily understood by all those involved in building the global database. Obviously, a typology that is so complex and sub-divided that every single situation requires a separate definition should be avoided. Instead, a certain minimum number of basic 'types' need to be agreed. Once a typology is agreed upon, then it is possible to debate, which 'types' of wastewater irrigation will be included and which excluded from the global assessment.

Typology of Wastewater Use

The following three types of wastewater use are the most relevant (Fig. 2.2):

Direct use of untreated wastewater is the application to land of wastewater directly from a sewerage system or other purpose-built wastewater conveyance system. Control exists over the conveyance of the wastewater from the point of collection to a controlled area where it is used for irrigation (Westcot, 1997). The irrigation source is wastewater that is directly taken from the sewerage system, or from stormwater drains that carry large sewage flows. An example of this situation is that found in Haroonabad, Pakistan, where untreated wastewater from a sewerage outlet

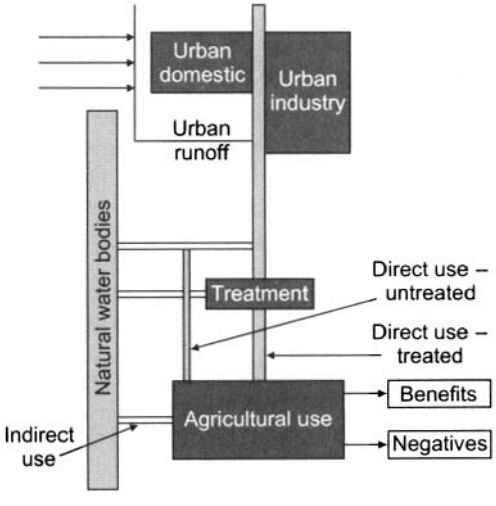

Fig. 2.2. Basic types of wastewater use.

is directly disposed on land where it is used for vegetable production (van der Hoek *et al.*, 2002). Another type of such use is when numerous informal irrigators draw water directly from the sewers or open drains, upstream of the site where disposal or treatment occurs. For example, this happens in Nairobi, Kenya, where farmers block sewers deliberately causing them to overflow (Cornish and Kielen, Chapter 6, this volume).

Direct use of treated wastewater is the use of treated wastewater where control exists over the conveyance of the wastewater from the point of discharge from a treatment works to a controlled area where it is used for irrigation. Many countries in the Middle East make use of wastewater stabilisation ponds to remove pathogens from wastewater. The effluent from the ponds is used for irrigation. To describe such a situation the term **reclaimed water** is often used, meaning water that has received at least secondary treatment and is used after it flows out of a domestic wastewater treatment facility. It must be noted that in many cases wastewater can only be considered partially treated to the design standard because the levels of wastewater production far exceed treatment capacity.

Indirect use of wastewater is the planned application to land of wastewater from a receiving water body. Municipal and industrial wastewater is discharged without treatment or monitoring into the watercourses draining an urban area. Irrigation water is drawn from rivers or other natural water bodies that receive wastewater flows. There is no control over the use of water for irrigation or domestic consumption downstream of the urban centre. As a consequence, many farmers indirectly use marginal quality water of unknown composition that they draw from many points downstream of the urban centre. In other cases the water is abstracted at one or two well defined sites for use in a **formal** irrigation system. An example of **indirect use of untreated** urban wastewater is found in Kumasi, Ghana, where large parts of the urban development have no operational sewerage or drainage network. A river passes through the urban centre and is progressively polluted by diffuse urban runoff. The water from this polluted river is abstracted by many users at many points downstream of the urban centre (see also Cornish and Kielen, Chapter 6, this volume).

Asano and Levine (1998) make the distinction between **wastewater reuse** which is the beneficial use of reclaimed (treated) wastewater and **wastewater recycling**, which normally involves only one use or user, who captures the effluent from the user and directs it back into the use scheme. Please note the assumption in this description that it is always treated wastewater. Wastewater reuse implies that the wastewater is used a second time. In fact, it is the water, not the wastewater that is being reused. Wastewater use therefore seems to be a better term than reuse, because the wastewater is generally used only once. Wastewater use can take place at the household level or off-site when there is a sewerage system.

As wastewater use can be defined as the deliberate application of urban wastewater for a beneficial purpose, it is in most cases *planned*, either by state agencies or farmers. However, there are also situations where natural rivers passing through cities become so heavily polluted with wastewater that they become *de facto* sewers. Asano (1998) describes the diversion of water from a river downstream of a discharge of wastewater as an incidental or unplanned reuse. Asano states that indirect reuse normally constitutes unplanned reuse whereas direct reuse normally constitutes planned reuse. There are important exceptions to this definition. For example, the effluent from the As-Samra treatment plant in Jordan ends up in an irrigation scheme after dilution in an intermittent stream locally known as a *wadi* and in a reservoir (McCornick *et al.*, Chapter 14, this volume). Although the scheme was never planned to use wastewater, it is clearly an irrigation scheme with planned development and managed by an irrigation agency that levies water tariffs. Along the Musi River in India irrigation schemes controlled by the Irrigation Department depend primarily on urban wastewater from the city of Hyderabad (Buechler, Chapter 3, this volume).

The distinction between planned and unplanned use does not seem to be of much practical relevance for the typology. Instead, it is suggested that the typology should indicate the main reason for use of the wastewater by farmers. In many cases the wastewater supply

is more reliable than other sources of irrigation water, or it may even be the only source of water that is available to farmers. In other cases it is the nutrients in the wastewater that make it attractive to farmers.

Another distinction that is often made is between formal and informal use. The concepts of formal and informal irrigation are, to some extent, synonymous with planned and unplanned irrigation. Formal irrigation could refer to the presence of an irrigation infrastructure or to a certain level of permission and control by state agencies. In most cases this will apply to a single point type of abstraction. If the abstraction of wastewater is at numerous scattered points, then it is unlikely that there is an irrigation infrastructure, and probably no control by state agencies, hence the wastewater use is informal.

Nationwide Assessments

The question is, 'Can the proposed typology be meaningfully applied at the national level? While there are only limited data available on the extent of wastewater irrigation, the salient features of wastewater use in some countries and the applicability of a typology can be described.

Pakistan

Pakistan has a rapidly growing population, that is expected to increase from 139 million in 1998 to 208 million in 2025. By that time, about 50% of the population will live in urban centres. In almost all towns in Pakistan that have a sewerage system, the wastewater is directly used for irrigation. IWMI has made a nationwide survey of wastewater use in Pakistan and the results indicate that 32,500 ha are directly irrigated with wastewater (Ensink *et al.*, 2004). A negligible proportion of this wastewater is treated and no clear regulations exist on crops that can be irrigated with wastewater. Vegetables are the most commonly irrigated crops, because they fetch high prices in the nearby urban markets. The wastewater used for irrigation is valued by farmers mainly because of its reliability of supply. In some cases the wastewater is auctioned by the municipal council to the highest bidder, often a group of richer farmers who then rent out their fields to poor landless farmers. Under these conditions, the use of untreated wastewater is considered a win-win situation by both the authorities that are responsible for wastewater disposal and the farmers who get a reliable supply of water with high nutrient content. There are therefore very few incentives to invest scarce resources in wastewater treatment.

India

The situation in the semi-arid parts of India is not much different from that in Pakistan, except that industrial effluent probably plays a bigger role. India has a population of one billion people (as of the 2001 census), with a population increase of 181 million during the 1990s alone. More than 28% of this population lives in cities with a percentage decadal growth in the urban population at 31%. Strauss and Blumenthal (1990) estimated that 73,000 ha were irrigated with wastewater in India. Surely, the typology used to obtain this estimate must have been different from the one used for China, where Mara and Cairncross (1989) estimated 1.3 million ha were irrigated with wastewater. Most wastewater irrigation in India occurs along rivers, which flow through such rapidly growing cities as Delhi, Kolkata, Coimbatore, Hyderabad, Indore, Kanpur, Patna, Vadodara, and Varanasi. Many of the Indian peninsular rivers would not have much or any flow during most of the year if they were not used to funnel wastewater away from cities to peri-urban and rural areas. In such cases this can hardly be considered disposal in surface waters as it is, in fact, disposal in a natural conveyance channel. Along the rivers the water is diverted via anicuts (weirs) to canals and often to tanks and then channelled to the fields for irrigation. If such uses were included, a much higher figure than 73,000 ha would be obtained, since for the area along one river, the Musi in Andhra Pradesh alone there are approximately 40,500 ha irrigated with wastewater.

Vietnam

Vietnam has a centuries-old tradition of using human waste in agriculture and aquaculture. Hanoi and other cities in the Red River delta have natural ponds that collect wastewater and drainage water from cities. These ponds are used for aquaculture and as sources of irrigation water, and also play an important role in flood control. While there are hardly any conventional treatment facilities, the natural ponds are likely to provide at least some purification of the wastewater. The ponds generally discharge wastewater directly into irrigation canal systems and rivers. Wastewater from city drains is also pumped into irrigation canal systems at certain times of the year, and at locations where there is insufficient irrigation water. Ongoing IWMI research in Vietnam shows that the area irrigated directly with urban wastewater is limited, but that indirect use after passage through natural ponds is widespread.

Mexico

Mexico accounts for about half of the 500,000 ha irrigated with wastewater in Latin America. Much of the recent scientific work on health impacts and other aspects of wastewater use has been done in Mexico. In most cases the wastewater is used at some distance from the urban centre in a formal irrigation setting. The bulk of the untreated wastewater from Mexico City goes to Mezquital, immediately north of the Mexico Valley where it is used for irrigation via an extensive network of irrigation canals. This is probably the largest and longest-standing wastewater use system in the world.

Jordan

In Jordan most of wastewater from urban areas is treated and used in agriculture. The As-Samra plant is one of the largest wastewater treatment plants in the world. It is a wastewater stabilisation pond system, consisting of 32 ponds occupying 200 ha and serving about half the population of the country. The benefits of this system have been well described. For example, aubergine yield under trickle irrigation with the effluent from the system was twice the average Jordanian aubergine production under freshwater irrigation using conventional fertilisers (Al-Nakshabandi *et al.*, 1997). This could be considered direct use of treated wastewater. However, much of the effluent is transported over long distances and is blended with rainwater stored in a reservoir. So indirect use of treated wastewater also takes place. A second point is the effectiveness of the treatment plants. Some treatment plants are clearly overloaded and the effluent from such plants could at best be called 'partially treated' if it is directly used. The effluent that is transported over some distance from overloaded plants receives a form of additional unintended natural treatment. There is no information on water quality from nationwide assessments so it is suggested that a very simple categorisation that includes 'treatment, but largely dysfunctional' is a possibility.

Global Database

Initially the database generated from the proposed global assessment of wastewater irrigation should provide estimates of the national and global areas irrigated with wastewater. As the database expands and more results of nationwide surveys become available, the possibilities for further analyses should be explored. For example, the area irrigated with wastewater in a country and the crops grown could be related to the total area irrigated and total agricultural production. A further step would be to estimate the impact of wastewater use on agricultural production, the economy in general, and livelihoods. Different scenarios could then be developed and their impact on agricultural production and the economy modelled.

Table 2.1 suggests a basic set of data requirements for the global database. Primary data collection will only be possible in a limited number of countries and the level of detail is therefore determined to a large extent by the availability of secondary data. To avoid the diversity of real-life situations being squeezed into a rigid format, any city-level description would need an additional description to the standard item scored.

Table 2.1. Proposed database outline for a global assessment of the extent of wastewater use in agriculture.

Type	Record	Field
General information	Country	Name
	City	Name
	Population size of city	Actual number
	Date of information	Calendar year
	Reference	First author, year
	Number of farmers/households involved in wastewater farming	Actual number
Use[a]	Direct – formal use	Area in hectares
	Direct – informal use	Area in hectares
	Direct use – total	Area in hectares
	Indirect – formal use	Area in hectares
	Indirect – informal use	Area in hectares
	Indirect use - total	Area in hectares
	No information on type of use available	Area in hectares
Treatment[b]	Conventional treatment	% of total area
	Natural/biological treatment	% of total area
	Treatment, but largely dysfunctional	% of total area
	No treatment	% of total area
	No information on treatment available	% of total area
Source	Municipal	Yes / No
	Industrial	Yes / No
	Mixed	Yes / No
Crops	Vegetables	Yes / No
	Rice	Yes / No
	Other cereals	Yes / No
	Fodder	Yes / No
	Cotton	Yes / No
	Fruit trees	Yes / No
	Ornamentals	Yes / No
	Pastures	Yes / No
	Fish/aquaculture	Yes / No
Reason for use	Only source of water available	Yes / No
	More reliable than other sources of irrigation water	Yes / No
	Supplies crop nutrients	Yes / No
Conveyance	Sewers or other formal collection network	Yes / No
	Other collection methods	Yes / No
	Natural drainage	Yes / No
Disposal	River or surface water body	Yes / No
	Irrigation	Yes / No
	Groundwater recharge	Yes / No

[a] Direct use: Wastewater conveyed to a defined area for irrigation, often single point type of abstraction from sewers or treatment plants.
Indirect use: Wastewater discharged into river or surface water bodies with numerous scattered points of uncontrolled downstream abstraction.
Formal use: Use of wastewater in an irrigation infrastructure with a certain level of permission and control by state agencies.
Informal use: Use of wastewater without an irrigation infrastructure (for indirect use) or irrigation lacking permission and control by state agencies (for direct use).

[b] In most cases the wastewater is untreated, i.e. not deliberately modified. In conventional wastewater treatment systems the wastewater is deliberately modified in order to obtain an effluent that is of better quality. In the case of natural/biological treatment such as natural ponds there is only limited or no control over retention time and other processes.

A reality check of data on the extent of area irrigated with urban wastewater can be obtained from a few typical scenarios that could apply to most countries. For example, assuming an annual rate of irrigation of 500 mm and per capita sewerage production of 100 l/day, a city of one million people would produce enough wastewater to irrigate an area of 7000 ha using efficient irrigation methods (Strauss, 2001).

Table 2.2 provides an overview of the information on the extent of wastewater irrigation that is currently available from a limited number of sources.

Limitations of the Typology

The proposed typology, like every typology, has limitations. It clearly focuses on those situations where (part of) cities have a conveyance system for wastewater, either sanitary sewers or stormwater drains that carry large sewage flows. There are, of course, many cities that do not have purpose-built sewers or drains. These obviously have a serious sanitation problem, but one could argue that for them the issue of wastewater use does not arise. Certain well-known types of wastewater use such as informal backyard (on-site) use of wastewater will have to be excluded from a global assessment because data are unlikely to be available. To document such practices, detailed case studies are likely to be more relevant than a global assessment. Certain types of on-site use are receiving increasing attention. These include the use of greywater, community-controlled decentralised wastewater disposal and use systems, and ecological sanitation. Obviously, in the countries where nationwide surveys can be organised, more details of wastewater use, on-farm conditions, and characteristics of the irrigators (men, women, children, socioeconomic status, ownership of land, land and water rights, etc.) can be collected.

Indirect wastewater use implies that there is a certain retention time and that certain processes take place before the water is used for irrigation. These include a certain die-off and removal of pathogens from the wastewater before its final use by the farmer. After a period of retention and at some distance downstream from the urban centre it is expected that the water quality improves, to the extent that it should no longer be called wastewater. However, there are at present no criteria to distinguish between: river water of good quality, polluted river water, and wastewater. In fact, the alternative to direct use of untreated wastewater is often the disposal of this wastewater in natural rivers and the two would be expected to have opposite effects on surface water quality. The disposal of untreated wastewater in rivers is an environmental problem, while one of the advantages of direct use of wastewater is that environmental (water) pollution is reduced.

Conclusions

In the foreseeable future, many towns in developing countries will continue or expand the direct or indirect irrigation of crops with untreated wastewater. Current government policies focus on regulation of wastewater use and wastewater treatment and are unable to offer practical solutions to the users. An important input into more realistic policies on wastewater use is information on the area irrigated with urban wastewater at national and global levels. Such macro-level estimates can only be obtained when there is a common understanding of the different types of wastewater use.

Table 2.2. Information currently available on the extent of wastewater irrigation from a limited number of sources.

Country/City	Population ('000)	Year	Farmers (number)	% of ww treated	Direct use (ha)	Indirect use (ha)	Vegeta-bles	Rice	Other cereals	Fodder	Fruit trees	Cotton	Fish	Reference
Afghanistan														
Kabul							Yes							Shuval *et al.*, 1986
Argentina														
Mendoza	320			100	3,700		Yes			Yes	Yes			Mara and Cairncross, 1989
Australia														
Melbourne				100	10,000									Mara and Cairncross, 1989
Bahrain														
Tubli					800									Mara and Cairncross,1989
Chile														
Santiago					16,000		Yes							Mara and Cairncross, 1989
Colombia														
Ibague	430					26,000		Yes						Young, 2002
Germany														
Braunschweig	325	1985	440	100	2,800									Mara and Cairncross, 1989
Ghana														
Accra		2001	700			300	Yes							Sonou, 2001
Kumasi	1,000	2000	12,700	0		11,500	Yes							Cornish and Aidoo, 2000
India														
Ahmedabad				0	890			Yes	Yes	Yes				Juwarkar *et al.*, 1988
Amritsar				0	1,214				Yes					Juwarkar *et al.*, 1988
Bhilai				100	607		Yes	Yes	Yes					Juwarkar *et al.*, 1988
Bikaner				0	40		Yes		Yes					Juwarkar *et al.*, 1988
Calcutta		1989	17,000	0		12,900	Yes	Yes					Yes	Mara and Cairncross, 1989; Edwards, 2001
Delhi	8,400	2001		52	1,214		Yes		Yes					Juwarkar *et al.*, 1988; Farooqui 2002
Gwalior				0	202		Yes	Yes	Yes					Juwarkar *et al.*, 1988
Hubli-Dharwad	800			0			Yes			Yes	Yes			Bradford, *et al.*, 2002.
Hyderabad	3,700	2001		24	110	40,500	Yes	Yes		Yes	Yes	Yes	Yes	Buechler and Devi, 2002
Jamshedpur				100	113				Yes	Yes				Juwarkar *et al.*, 1988
Kanpur				0	1,300		Yes	Yes	Yes					Strauss and Blumenthal, 1990
Lucknow				0	150		Yes	Yes						Juwarkar *et al.*, 1988

Table 2.2. Continued.

Country/City	Population ('000)	Year	Farmers (number)	% of ww treated	Direct use (ha)	Indirect use (ha)	Vegeta-bles	Rice	Other cereals	Fodder	Fruit trees	Cotton	Fish	Reference
Madras				0	133					Yes				Juwarkar *et al.*, 1988
Madurai				0	77					Yes				Juwarkar *et al.*, 1988
Nagpur				0	1,500		Yes	Yes	Yes	Yes				Juwarkar *et al.*, 1988
Trivandrum				0	37					Yes				Juwarkar *et al.*, 1988
Vadodara	1,400	2002		0		14,567			Yes			Yes		Bhamoriya, 2004
Iran														
Teheran							Yes							Shuval *et al.*, 1986
Kenya														
Nairobi	2,000		3,700	0	2,000		Yes	No	No	No	No	No	No	Hide and Kimani, 2000
Kuwait														
Kuwait		1986		100	9,000		Yes			Yes				Shuval *et al.*, 1986
Mexico														
Alfajayucan		2000	19,540	0	33,051									Scott *et al.*, 2000
Atoyac-Zahupan				30	3,800									Peasey *et al.*, 2000
Cienega de Chapala				0	10,469									Peasey *et al.*, 2000
Cindad Juarez				0	7,503									Peasey *et al.*, 2000
Chiconautla				0	3,123									Peasey *et al.*, 2000
Culiacan				0	800									Peasey *et al.*, 2000
Delicias				0	589									Peasey *et al.*, 2000
Estado de Jalisco				0	13,077									Peasey *et al.*, 2000
Estado de Mexico				0	5,498									Peasey *et al.*, 2000
Estado de Morelos				10	23,000									Peasey *et al.*, 2000
Guanajuato		2000		0		140								Scott *et al.*, 2000
Irapuato	300			83										Buechler and Scott, 2000
La Antigua				0	1,000									Peasey *et al.*, 2000
Lazaro Cardenas				0	21,899									Peasey *et al.*, 2000
Leon	1,100	1995			3,030				Yes	Yes				Chilton *et al.*, 1998
Mexico City				11		350,000				Yes				Peasey *et al.*, 2000
Mezquital Valley		1995	45,000			90,000	Yes		Yes	Yes				Chanduvi 2000; Cifuentes *et al.*, 2000
Quitupan Magdalena				0	5,000									Peasey *et al.*, 2000
R. Lago				0	1,600									Peasey *et al.*, 2000

Table 2.2. Continued.

Country/City	Population ('000)	Year	Farmers (number)	% of ww treated	Direct use (ha)	Indirect use (ha)	Vegeta-bles	Rice	Other cereals	Fodder	Fruit trees	Cotton	Fish	Reference
Rio Blanco				1	13,000									Peasey *et al.*, 2000
Rio Colorado				0	69									Peasey *et al.*, 2000
Rosario-Mezq.				0	33,080									Peasey *et al.*, 2000
San Juan del Rio				100	230									Peasey *et al.*, 2000
Santo Domingo				0	22									Peasey *et al.*, 2000
Tepecuac y Q.				0	100									Peasey *et al.*, 2000
Tula			31,316	0	45,125									Scott *et al.*, 2000
Tulancingo				0	300									Peasey *et al.*, 2000
Tuxpan				10	4,300									Peasey *et al.*, 2000
Valsequillo				87	20,600									Peasey *et al.*, 2000
Xicotencatl				0	2,300									Peasey *et al.*, 2000
Zamora				0	2,000									Peasey *et al.*, 2000
Morocco														
Beni Mellal	210	1993			600		Yes		Yes		Yes			Habbari *et al.*, 1999
Pakistan														
Arif Wala	74			0	300		Yes	Yes		Yes		Yes		van der Hoek *et al.*, 2002
Bahawanagar	111			0	55		Yes			Yes				van der Hoek *et al.*, 2002
Bahawalpur	408			0	600		Yes							van der Hoek *et al.*, 2002
Burewala	153			0	500		Yes		Yes	Yes		Yes		van der Hoek *et al.*, 2002
Faisalabad	2,000		2,000	0			Yes							Ensink, J., 2003.
Fort Abbas	35			0	100		Yes							van der Hoek *et al.*, 2002
Haroonabad	63		80	0	150		Yes			Yes		Yes		van der Hoek *et al.*, 2002
Khairpur	27			0	25		Yes			Yes				van der Hoek *et al.*, 2002
Minchinabad	26			0	12			Yes						van der Hoek *et al.*, 2002
Vihari	94			0	160		Yes		Yes	Yes		Yes		van der Hoek *et al.* 2002
Peru														
Chiclayo		1991		0	390									Chanduvi, 2000
Ica		1989		100	530									Mara and Cairncross, 1989
Lima		1987		2	6,800		Yes			Yes	Yes	Yes		Chanduvi, 2000; Mara and Cairncross, 1989
Piura		1991		100	116									Chanduvi, 2000
Tacna		1991		100	210		Yes							Strauss and Blumenthal, 1990

Table 2.2. Continued.

Country/City	Population ('000)	Year	Farmers (number)	% of ww treated	Direct use (ha)	Indirect use (ha)	Vegeta-bles	Rice	Other cereals	Fodder	Fruit trees	Cotton	Fish	Reference
Trujillo	400	1989		0	1,300									Mara and Cairncross, 1989
Saudi Arabia														
Riyadh					2,850									Mara and Cairncross, 1989
South Africa														
Johannesburg					1,800									Mara and Cairncross, 1989
Sudan														
Khartoum				100	2,800									Mara and Cairncross, 1989
Tunisia														
Tunis				100	4,450		Yes			Yes	Yes			Mara and Cairncross, 1989
USA														
Bakerfield, California					2,250									Mara and Cairncross, 1989
Chandler, Arizona					2,800									Mara and Cairncross, 1989
Fresno, California					1,625									Mara and Cairncross, 1989
Kearny, Nebraska				100	1,200									Mara and Cairncross, 1989
Lubbock, Texas					3,000									Mara and Cairncross, 1989
Muskegon, Michigan					2,000									Mara and Cairncross, 1989
Santa Rosa, California					1,600									Mara and Cairncross, 1989
Vietnam														
Bac Ninh	76	2001		0		100	Yes	Yes					Yes	Doan Doan Tuan, 2001
Ha Tinh	57	2001		0		223	Yes	Yes					Yes	Doan Doan Tuan, 2001
Hanoi	2,736	2001		0		1,560		Yes					Yes	Doan Doan Tuan, 2001
Ho Chi Minh	5,169	2001	4,000	0		1,000	Yes	Yes						Doan Doan Tuan, 2001
Ninh Binh	63	2001	1,400	0		304								Doan Doan Tuan, 2001
Thai Binh	132	2001		0		355	Yes	Yes						Doan Doan Tuan, 2001
Thanh Hoa	179	2001		0		360	Yes	Yes					Yes	Doan Doan Tuan, 2001
Viet Tri	132	2001		100		200	Yes	Yes						Doan Doan Tuan, 2001

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3 A Sustainable Livelihoods Approach for Action Research on Wastewater Use in Agriculture

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Abstract

The dearth of holistic studies that use a combination of technical and socio-economic, quantitative and qualitative methodologies impedes advances in the formulation of recommendations that could enhance the benefits and mitigate the harmful effects of wastewater use for both producers and consumers of wastewater-irrigated crops. New research based on a sustainable livelihoods framework can integrate multiple perspectives. Sustainable livelihoods analyses are actor-centred and can be used for studies on the socio-economic and biophysical context surrounding wastewater use and users in a given area. This chapter draws on case study material from Hyderabad, India and Irapuato and Chihuahua, Mexico.

A multi-disciplinary approach is imperative in studies of wastewater use so that both the public and private sectors, farmers and consumers can be informed about: 1. the livelihood activities of different stakeholder groups that are sustained by wastewater, 2. the benefits and risks of its use, and 3. the options available to manage such use more effectively. Currently, there is a dearth of holistic studies that include both technical and non-technical research on a particular wastewater use area. This impedes advances in the formulation of recommendations for the use and management of wastewater. Such studies could enhance the benefits and mitigate the harmful effects for wastewater-dependent people and for consumers of wastewater-irrigated produce. New research on wastewater use that utilises a sustainable livelihoods (SL) framework of analysis, can address issues hitherto neglected in social scientific studies. The SL approach can also, it is argued here, begin to be used to bridge the divide between technical and non-technical studies.

The Sustainable Livelihoods Approach

A livelihood is comprised of the capabilities, assets (including both material and social resources) and activities required to make a living (Chambers and Conway, 1992). Livelihoods are based on income (in cash, kind, or services) obtained from employment, and from remuneration through assets and entitlements. In 1987, a report by an advisory panel of the World Commission on Environment and Development (WCED) stressed the need for a new concept to address both equity and sustainability and termed it 'sustainable livelihood security'. Robert Chambers, Gordon Conway and others working with the Institute

 Wastewater Use in Irrigated Agriculture
(eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

of Development Studies (IDS) and the International Institute for Sustainable Development (IISD) developed the Sustainable Livelihoods (SL) approach from the mid-1980s onwards to bridge initiatives centred on the environment, development and livelihoods. The SL approach builds on the Integrated Rural Development (IRD) model, participatory development and basic needs approaches, food security studies, and sector-wide approaches (DFID, 2003) and incorporates other types of analyses related to households, gender, governance and farming systems to arrive at a more holistic understanding of poverty (Farrington *et al.*, 1999). Chambers noted that:

> 'Professions and the Government Ministries and Departments which preserve and accentuate their specialisation, focus quite narrowly, overlooking linkages which are often important for resource-poor farmers. Agroforestry, meaning the interaction of trees and crops and/or livestock is a classic example where agronomists are concerned with crops, not trees or livestock; animal specialists are concerned with animals, not trees or crops; and foresters are concerned with trees, not crops or animals, and moreover trees in forests and not trees on farmers' lands'. Chambers (1987).

The SL approach shifted the focus to poor people to overcome this overly narrow type of analysis. The focus on people rather than on resources, structures, or physical areas entails a bottom-up approach that encompasses both the macro- (policy) and micro- (users, field) levels. Chambers (1987) argued that the emphasis placed on physical problems rather than on people hindered research as well as development projects that aimed at achieving sustainability.

Chambers and Conway's work focused on how rural households and members within households diversify their activities to increase income, reduce vulnerability and improve the quality of their lives. They argued that a livelihood is sustainable if it:

> '... can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and ... contributes net benefits to other livelihoods at the local and global levels and in the short and long-term' (Chambers and Conway, 1992).

Livelihood activities of the poor are dynamic and context-specific. The SL approach includes an analysis of the vulnerability of the poor which results from 'sudden shocks, long-term trends or seasonal cycles' as discussed by Moser (1996) and can be studied by examining such assets as labour, social and human capital, productive assets, and household relations (Moser and Holland, 1997).

One of the main reasons why the SL approach was developed was to foster the incorporation of the poor, women, and those in rural areas into research and into development programmes (Chambers, 1987). Livelihood strategies often remained invisible to both researchers and development specialists. This stemmed partly from the fact that different members of a household engage in different types of livelihood activities. Each household member above a certain age attempts to procure different sources of food, fuel, animal fodder and cash; these sources are likely to vary according to the month of the year. Therefore, researchers need to ask each household member about these activities, and to include the changes incurred by season and by household life cycle stage.

The scale of analysis can be at the micro- and meso-levels of the individual, household, kin networks, village, or region, or at the macro-level of the nation (Scoones, 1998). A livelihoods framework of analysis is unusual in that it fosters the study of macro–meso–micro linkages. These linkages include how macro-level policies affect the livelihood options of poor individuals and communities as well as how the poor affect policies and institutions. Such research can provide policymakers and planners with critical information that can improve the efficacy of poverty alleviation programme and policies. This chapter will address how the approach can be used to study macro-, meso- and micro-level issues pertaining to wastewater use.

In the late 1990s, Scoones at IDS centred his work on the institutional processes (formal and

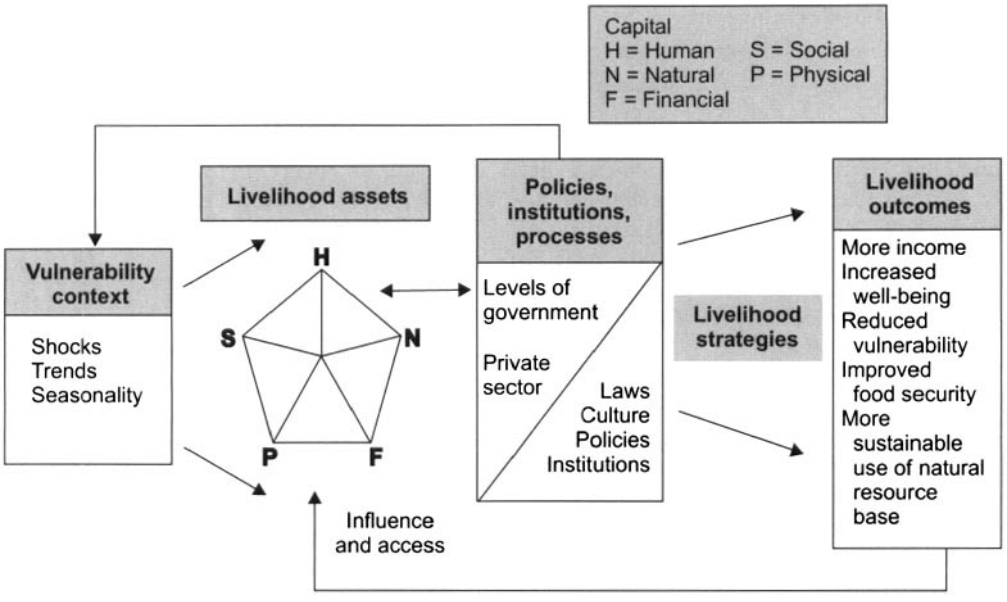

Fig. 3.1. Sustainable Livelihoods Framework.
Source: DFID, 2003

informal institutions and organisations) which enable or act as a barrier to achieving positive livelihood outcomes (Scoones, 1998). The SL approach was adapted for the study of urban areas by Caroline Moser (1998) and John Farrington *et al.* (2002) by shifting the focus from natural assets and environmental sustainability for the study of rural areas to households, housing and financial assets for the study of urban areas (Farrington *et al.*, 2002). The interconnectedness of urban, peri-urban and rural livelihood systems incurred through remittances, short-term migration and daily or seasonal labour was also illuminated (Sharma, 1986; Barret and Beardmor, 2000; Satterthwaite and Tacoli, 2002 in Farrington *et al.*, 2002).

Livelihoods, Water Availability and Wastewater Use

Most livelihood activities depend on the availability of water. However, in many semi-arid and arid regions of the world, freshwater is a scarce resource. Fresh surface water is usually also only available in sufficient quantities during the rainy season. But, the rainy season may only last for 4 months during which rainfall can be erratic, necessitating irrigation. Water for irrigation is also required for the long dry season. Groundwater may be expensive to access because of low water tables that translate into the high costs associated with drilling wells and pumping the water. Seeking other sources of water to support livelihoods therefore becomes critical to the question of poverty reduction. Near urban centres wastewater is often available year-round in sufficient quantities. It is in this context that wastewater needs to be studied as natural capital required to sustain the means of living in arid and semi-arid, drought-prone areas.

In many arid and semi-arid regions, wastewater use may either be the only option, or the only economically viable option available to many groups of people. Livelihood activities directly dependent on wastewater are practised by different social groups on

different scales and include (but are not limited to) agriculture, agro-forestry, livestock rearing, aquaculture, floriculture, and the washing of clothes[1]. Activities indirectly dependent on wastewater include the sale of seeds, pesticides and other inputs to wastewater farmers, rental of harvest machinery or equipment, agricultural labour, services related to the transportation of produce to markets, marketing produce, animal husbandry with purchased wastewater-irrigated fodder and the provision of fish seedlings for pisciculture.

The amount of wastewater produced depends on the population of a city or town. Industrial and domestic liquid wastes are frequently channelled either into the same sewerage system (if a sewerage system exists) or into the same open drains. Wastewater quality is affected by the volume and types of industrial effluent released into the sewerage system or drains, and the degree of dilution with domestic water and natural sources of flow where these exist. The wastewater is either released untreated, after partial treatment, or after more complete treatment (to the secondary or tertiary levels), into drains, into channels, and then frequently into rivers.

There is no simple solution to wastewater use or how to minimise its negative consequences. What seems transparent and evident is that the wastewater must be treated. However, building, operating and maintaining treatment plants is very costly and can drain a government's financial resources. Even if growing cities were able to afford to treat all of the domestic and industrial wastewater they produce (about 80% of the water delivered to an urban area comes out of the city as wastewater), urban water authorities often want to use the treated water within the city for watering public parks and other urban areas in order to save the costs of drilling wells and pumping groundwater for such uses. Urban water authorities also often wish to recover costs by providing treated wastewater to users who can pay a fee for it, such as golf course operators and upper-class residents who use it to water their gardens. Thus smallholders or landless people, who rent land to cultivate crops, can lose access to a resource critical to their livelihoods, and consumers can be deprived of cheap, fresh produce. This is happening in the arid city of Chihuahua, Mexico (Horacio Almazán Galache, 2003, personal communication).

Current Approaches to Social Scientific and Biophysical Studies

Socio-economic studies on wastewater irrigation that address livelihood issues have just begun to gain currency. Some of the economic benefits accruing to farmers from wastewater-irrigated crops have been documented by Keraita *et al.* (2002), Niang *et al.* (2002), Cornish and Aidoo (2000) and others. Socio-economic analyses of groundwater users in wastewater-irrigated areas and the political and institutional arena in which wastewater production, treatment and use occurs, for example, are just beginning to appear in the literature (Cirelli, 2000; Peña, 2000; Abderrahman, 2001; Buechler, 2001; Keraita *et al.*, 2002; Ouedraogo, 2002; Buechler and Devi, 2003a; Chandran *et al.*, 2003; Parkinson and Tayler, 2003; Shetty, Chapter 15 this volume). The socio-cultural acceptability of wastewater use in Palestine was addressed by Khateeb (2001). The health effects of wastewater production and the social and economic consequences of these effects for wastewater farmers, agricultural labourers and their household members and consumers of wastewater-irrigated produce have also been studied in some areas (Shuval *et al.*, 1986; Blumenthal *et al.*, 2000; Feenstra *et al.*, 2000; van der Hoek *et al.*, 2002; Ensink, 2003). Many of the health studies, however, lack what Mara and Cairncross called for in their well-known *Guidelines for the Safe Use of Wastewater in Agriculture and Aquaculture* (WHO, 1989), that is, 'a thorough assessment of the local socio-cultural context'.

[1] Washing clothes in wastewater, e.g. in Hyderabad and Madurai, India, tends to occur only in the rural areas downstream of urban centres where wastewater quality is better. It tends to be practised by hired clothes-washers rather than by individual households who prefer to use groundwater.

Social scientific studies on wastewater to date report basic background information on climate and average rainfall, together with data on the various sources, quality and quantity of industrial and domestic sources of wastewater. Such studies foster an understanding of the risks associated with this use for a particular user group. However, they rarely integrate more-advanced information on the spatial distribution of precipitation and wastewater availability, yet social groups dependent on wastewater for their various livelihood activities are deeply affected by these complex interactions. Therefore, a more holistic picture is necessary. The types of crops, livestock, and fish that farmers can raise are affected by the quality of the wastewater and the characteristics of the natural environment. In hot climates with a long dry season high rates of evaporation cause wastewater to be more saline with high total dissolved solids (TDS) concentration that may restrict the variety of crops that can be cultivated. Since many types of grass fodder can be grown with saline wastewater, this water is more likely to be used in urban and peri-urban areas for fodder production, particularly where there is an urban demand for dairy products as is the case in India and Mexico.

The impacts of such imposed choices, though, are not limited to a change in cropping practices. With deteriorating wastewater quality, the health of the livestock may be seriously impaired as is currently the case near Hyderabad, India and the quality of their milk may be affected which may transfer the danger to humans. The dairy producers' income may decrease if there are reductions in milk production per animal. Similarly, many varieties of fish are sensitive to changes in water quality and the varieties of fish raised by fisherfolk in a sewage pond would need to be changed if the water quality deteriorated (Buechler and Devi, 2002a). The SL approach offers a way in which to assess the vulnerability context of those who depend on wastewater. Shocks, trends and seasonality all define the context of vulnerability in this approach and can be applied to sudden, gradual or seasonal deterioration in the quality of wastewater.

Biophysical studies on wastewater often focus on industrial and domestic wastewater treatment technologies (van Lier and Lettinga, 1999; Jindal *et al.*, 2003; Mullai and Sabarathinam, 2003; Environline, 2003) or on wastewater quality (Goewie and Duqqah, 2002), groundwater quality in wastewater-irrigated areas (Farid *et al.*, 1993; Haruvy, 1997; Chilton *et al.*, 1998; Gallegos *et al.*, 1999), soil contamination and remediation in wastewater-irrigated areas (Jeyabaskaran and Sree Ramulu, 1996; Mendoza *et al.*, 1996; Gupta *et al.*, 1998), heavy metal uptake in wastewater-irrigated crops (Chino, 1981; Mitra and Gupta, 1999; Rattan *et al.*, 2002), bacteriological analyses (Sinton *et al.*, 1997), helminth infection in wastewater users (Srivastava and Pandey, 1986; Blumenthal *et al.*, 2000; Peasey, 2000) and GIS analyses of wastewater-irrigated areas (Palacio-Prieto, *et al.*, 1994; Buechler and Scott, 2000; Nobel and Allen, 2000; Aramaki, 2001).

Assessing the social, political, economic and technical applicability of technical and management solutions for particular wastewater-related practices becomes difficult, if not impossible, with purely biophysical analyses. Essential data, for example, on the capacity of varied social groups or communities and of individual women or men within these to invest labour, capital and time in certain management techniques and technologies is invariably lacking. Similarly, information on the organisations and institutions that govern wastewater use is required, particularly on whether or not they have the necessary financial and institutional capacities, willingness and political clout to implement new management strategies in a sustainable manner.

Research conducted in urban, peri-urban and rural areas near Hyderabad city, India, shows that such socio-economic characteristics as caste, class, ethnicity, gender and land tenure influence the type of wastewater-dependent livelihood activities in which each person engages (Buechler and Devi, 2002a; Buechler *et al.*, 2002; Buechler and Devi, 2003b, c). At present, the barter and sale of vegetables in the wastewater-irrigated urban and peri-urban areas is controlled by women and improves their ability to gain access to a wider variety of vegetables for themselves and for their household members. Recommendations based on biophysical studies that include a switch in crops from leafy vegetables to tree crops might

have ramifications for women's income-generating capabilities and food-security status. Toddy (fermented palm juice) production and fishing are practised currently only in rural areas downstream of Hyderabad and are controlled by men of particular caste groups. Therefore, it would be difficult to promote these as alternative income-generating schemes for other social groups. Technical studies critical of profligate water use for paddy rice production near Hyderabad must take into consideration that the food security of smallholders, of landless people who rent land for paddy rice production, and of landless labourers is dependent upon paddy rice production in the rural areas. Farming families are often already innovating by changing cropping patterns (Buechler and Devi, 2002b) or are mixing groundwater with wastewater to improve the overall quality of the water (Buechler and Devi, 2003a).

Sustainable wastewater use means that this resource will serve as a reliable asset for livelihoods now and in the future. This would require wastewater to be of a sufficiently high quality, so that it will not damage the natural environment or the agriculture practised using this resource. The interplay between wastewater users, agriculture, agroforestry, animal husbandry and aquaculture on the one hand, and soil, plant and wastewater quality on the other, needs to be elucidated through an integrated, holistic conceptual framework.

SL Approach for Integrating Problem Identification and Management Recommendations

In seeking pragmatic solutions to sustainable wastewater use, the need for holistic studies incorporating the missing dimensions cited above becomes clear. Using a livelihoods approach for wastewater use studies would centre research on the actors[2] who directly or indirectly benefit or are put at risk from wastewater. Of particular importance are decision-making processes pertaining to wastewater management and livelihood choices. A livelihoods approach views livelihoods as dynamic rather than static. Actors decide how best to adapt wastewater-dependent livelihood activities to changing external conditions. These include changes in wastewater availability, improvements in or deterioration of wastewater quality, and new government incentives or disincentives related to crop production. Changes in wastewater-dependent livelihood activities in turn require new decisions on how best to manage wastewater. These decisions will be influenced by social, economic, political, institutional, legal, and health-related factors as well as by environmental and technical factors. Livelihood analyses that include a study of the reasons behind actors' decisions to initiate changes in wastewater-dependent livelihoods over time will produce a more integrated understanding of wastewater management at different levels (individual, household, village, city, and potentially, even region and nation) leading to more appropriate policy recommendations for the present and future (see Box 3.1).

Methods Used in Livelihoods Analysis

In order to procure rich data that is actor-centred and interdisciplinary, research methodologies must be diverse. Both socio-economic and biophysical data can be collected through field observations, water, soil and plant sampling and analysis, rapid appraisal techniques, geographic information systems, various mapping techniques including vulnerability analysis and mapping tools, focus group discussions, surveys with closed and open-ended questions and in-depth interviews with different categories of representatives and users responsible for wastewater management at different levels in intra-urban, peri-urban, and rural areas. As part of the surveys and interviews, some key questions eliciting the users' perceptions on wastewater dependency for livelihoods need to be recorded, transcribed

[2] I use the term 'actor-centred' rather than 'people-centred' approach in this chapter because I believe that this is a more comprehensive term that more clearly connotes the inclusion of individuals and institutions and organisations as the units of analysis, enabling both micro- and macro-level analyses.

Box 3.1. Critical Questions for the Analysis of Wastewater Management using an SL Approach

- **Who** is earning or saving income through direct wastewater use or through secondary activities that are dependent on wastewater-derived products? (Gender, caste, class, ethnicity, religion, land-tenure characteristics of the direct users and others who gain an income or save money from wastewater-dependent activities).
- **Why** does each social group depend on the wastewater? (Lack of other water sources, drought, lack of financial resources to use other water, and need for: dependable, year-round water, nutrients in wastewater to reduce fertilizer costs, more fertile soil, etc.).
- **For which activities** are varied groups using this water and what types of secondary activities are generated that create a chain of economic beneficiaries? (Primary activities include agriculture on rented or family land, agroforestry, aquaculture, domestic use and recreation. Secondary activities include livestock rearing and dairy production, agricultural labour [casual, migrant and permanent], transportation to and sale of products in markets, etc.).
- **What are the positive and negative implications** of this wastewater use now and for the future? (For socio-economically distinct women, men, and children and their livelihoods, for agricultural workers' health and the health of their household members, for consumers' health and for the quality of water, soil and plant resources in the downstream area).
- **What management measures** at the community, local, regional and national levels by individuals or by those acting within institutions (informal and formal) mitigate risks and ensure sustainability of this use? Who are the most vocal actors in these organisations?
- **What alternatives to current management practices could be proposed at different levels?** (Improve identification and wider dissemination of farming households' innovations; work with industry to decrease amount of water used, to treat effluent and to reuse chemicals; improve water retention rates such as in storage tanks/ponds before irrigation, change irrigation and harvesting methods and promote decentralized, affordable treatment systems).

and used as integral parts of written text and audiovisual media (video, radio, and television) so that use patterns can be better understood. Interviews must be conducted with more than one household member of different genders and ages.

The next sections identify the main units of analysis and some major issues in the study of wastewater users using an SL approach.

Macro-level

SL analyses at the macro-level focuses on wastewater use in a basin context. By studying the river from its source to its confluence with other rivers, or its outlet to the sea, use patterns by different actors that affect wastewater quantity and quality downstream can be discerned. If significant amounts of the water are abstracted for livelihood activities (and industrial use) upstream, there may be less water available for the city and therefore less wastewater generated by the city. Industrial contamination upstream of, within, and downstream of the city can affect wastewater users since it will place limitations on the types of livelihood activities in which they can engage. Inter-basin transfers must be considered when urban areas that can obtain water even from other basins grow rapidly, and release increasing volumes of wastewater. By including institutions and organisations regulating intra- and inter-basin water abstraction and use in basin-level analyses, light can be shed on how actors within them mediate the use of natural capital in the basin.

Livelihood activities near cities sometimes consume the entire amount of wastewater being discharged by the urban area as is the case with the Musi river in Andhra Pradesh, India. All of the wastewater in the Musi is used before its confluence with the Krishna, a major river that flows into the Bay of Bengal (Buechler and Devi, 2002a). Studies employing a SL approach would complement other types of studies that set the macro-level context in which wastewater use is inserted from a historical, macro-economic, political, institutional or socio-cultural perspective or a hydrological (water balance, water quality), agronomic or animal husbandry perspective.

Meso-level

At the meso-level, an important unit of analysis for SL studies on wastewater is the wastewater delivery system. The delivery system can be composed of the river itself and/or man-made infrastructure, such as pipes and culverts, open or closed sewer canals, storm drains, canals, earthen channels, diversion weirs, ponds and wells, that delivers or stores the water in each area. Technical and institutional perspectives should be incorporated into this level of analysis. The delivery system may extend beyond the peri-urban areas, therefore it is important that the urban to peri-urban to rural transect be investigated. Large cities like Hyderabad, or even medium-sized cities such as Irapuato in Mexico frequently produce enough wastewater to sustain livelihoods in the rural areas (Buechler, 2001; Buechler and Devi, 2003b). The infrastructure is likely to be different at each location and tailored to suit such local livelihood needs as labour costs and availability, cropping patterns and crop water requirements and such environmental conditions as the availability and topography of the land, flow rates and soil types together with micro-climatic conditions such as temperature and rainfall patterns. The delivery system constitutes a crucial component of the physical assets to which people have or do not have access; this access is influenced by their access to other assets.

In order to understand the manner in which this infrastructure is built, operated and maintained, the meso-level organisations (and micro-level institutions and organisations, see below) surrounding these structures for channelling the water must be identified and researched. The SL approach is a useful tool to analyse the ways in which policies, institutions and processes help shape livelihood outcomes. Formal and informal institutions at various levels are both shaped by and help mould the natural, social, economic and political environment in which wastewater users and their livelihoods are inserted. Institutions should be studied as 'complexes of norms and behaviours at the village (and higher) level that persist over time by serving some collectively valued purpose' (Uphoff, 1992). The various wastewater-dependent actors who follow these 'norms and behaviours' or, what North (1990) has termed the 'rules of the game', group together into organisations that influence wastewater management in different, and at times, conflicting ways.

At the meso-level, the roles of actors within governmental, non-governmental and private-sector organisations in controlling water pollution and regulating wastewater use (by either encouraging, passively allowing, or actively discouraging it) need to be studied. Pollution control boards, metropolitan water and sanitation boards and irrigation departments may all play important roles in waste and wastewater management but some of these roles may not be immediately obvious. The *de jure* and *de facto* functioning of various actors with positions in governmental agencies responsible for wastewater management requires attention because the two may be very different. What is legally sanctioned may differ widely from the everyday practices of the actors within the organisations. These practices will affect how the wastewater is actually managed. The work of researchers and practitioners in non-governmental organisations that operate at a regional level should also be included in analyses especially those that have programmes addressing infrastructure development, land and water access, agricultural extension, occupational training, public health, etc. Non-governmental programmes targeting issues concerning gender, religion, occupation/caste/class and income may also serve wastewater-dependent people and aid them in wastewater management for livelihoods in

specific ways that are to date not well understood and therefore not replicated.

Employing a SL approach which combines technical and institutional analysis at the meso-level ensures that infrastructure will be viewed as a dynamic tool that can influence livelihood outcomes. Changing such conditions as wastewater quantity and/or quality will change the ways in which people make use of the existing infrastructure and may even create demand for physical changes to it. For example, near Irapuato, Mexico, farmers pressured the government to build an additional canal branch from the city wastewater drainage channel to their peri-urban fields when wastewater volumes became substantial (Buechler, 2001). It must be understood that infrastructure related to wastewater delivery is continuously adapted by actors to serve livelihood needs. Those in certain positions of power (with greater political and often financial capital) or those who are connected to people in powerful positions (with greater social capital) have greater opportunities to adapt this infrastructure to their own or to their supporters' specific and current livelihood needs (Cirelli, 2000; Peña, 2000).

Micro-level

At the micro-level, the following units of analysis help reveal and interpret livelihood activities present in a given area:

1. The chain of economic beneficiaries that are dependent on wastewater
2. Households
3. Infrastructure from which the wastewater is extracted (drainage culvert, pipe, river, canal, pond, etc.) and channelling methods used
4. The local institutions that shape local wastewater use.

The chain of economic beneficiaries

A chain of economic beneficiaries from wastewater-dependent activities is formed by those who benefit directly or indirectly from the production, use and/or sale of wastewater-irrigated products. As discussed at the beginning of this chapter, those directly dependent on wastewater include farmers involved in agriculture and agroforestry together with fisherfolk, and those who depend indirectly are dairy producers who use wastewater-irrigated fodder, migrant and non-migrant agricultural labourers who work in wastewater fields, vegetable and fodder market vendors who sell wastewater-irrigated produce, and transporters of this produce. Some of these actors have fewer overall assets than others and some have more diversified income sources than others. In analysing this chain, the point of departure is the wastewater-derived product that is traced from its origins to the marketplace and then to the consumer. However, using an agricultural commodity chain analysis is not sufficient because it may not capture non-market benefits of wastewater production such as the use of wastewater-irrigated fodder for the farmer's own livestock or household consumption of the food produced. It is also unlikely to capture that one household member may derive benefits from multiple wastewater-produced commodities. Development programmes and policies need to be able to identify the separate links in this chain and to understand the nature of the connections between the links.

Household-level analysis that examines the role of each constitutive member

At the micro-level, the household is the key unit of analysis. The SL approach uses the household as an important unit of analysis but also stresses the importance of disaggregating the household in order to be able to understand the role of each member in livelihood creation. The composition of the class, caste, gender, age, ethnicity and religious affiliations of its members are likely to affect the household's principal activity related to wastewater. The location of the parcel of land in terms of its elevation with respect to the wastewater channel(s), i.e. the value of the land which is an indicator of the household's class position, will determine whether pumping from the channel is necessary influencing the profitability of the agriculture. The landholding status of the adults in a household as landowners, land leasers, landless labourers or a combination of these also affects the types of crops they grow,

the profitability of agriculture or other income-generating activities, and the diversification of livelihood strategies by household member. The number and types of livestock the household owns (part of their physical capital) will influence the types of wastewater-related activities in which they engage (such as fodder production) (Buechler and Devi, 2002a). Caste still plays an important role in India in shaping each person's type of employment. From birth, for example, boys from the *Gouda* community, considered to be a low caste, learn toddy[3] tapping from their fathers (girls cannot become toddy tappers). However, educational opportunities and affirmative action programmes are expanding the types of employment that the young can obtain. Gender is likely to shape the power of each member to negotiate which wastewater-related activities to engage in and which person will retain the earnings from those activities. One example is vegetable production, which is mainly done by women in some areas, e.g. the peri-urban area of Hyderabad city (Buechler and Devi, 2002a) and by men in other areas, e.g. Kumasi, Ghana (Cornish and Kielen, Chapter 6, this volume). Ethnicity also shapes the types of wastewater-related activities in which people are engaged, e.g. the *Lambadis*, a nomadic tribal group in India, often work as landless agricultural labourers in wastewater-irrigated fields. Religion frequently plays a role especially influencing the type of animals raised and whether or not people engage in agriculture or the trading of agricultural commodities. One of the main reasons the SL approach was developed was to draw attention to the role of women and the poor in livelihood creation.

Frequently, the different types of labour necessary to perform each particular activity vary by gender and age of the constitutive household members (e.g. women and children mainly provide water for domestic use, while men tend to be more involved than women in irrigation; men tend to predominate in fodder grass production and women and children in feeding the fodder to buffaloes and cows). The type of remuneration for each of these activities varies across different categories of people and different types of activities. Women tend to be remunerated at a lower rate than men for the same or more labour-intensive activities. Household food security may be enhanced if payment is made in kind. In the wastewater-irrigated paddy rice fields near Hyderabad, in-kind payment in rice helps ensure that male labourers from drought-prone and other areas contribute to household dietary requirements rather than spending their wages on alcohol (Buechler and Devi, 2003c). The stage in the household life cycle[4] and the total number of members able to undertake income-generating and income-saving activities also determines whether or not the household as a unit can afford to engage in labour-intensive activities. Low-income households cannot afford to hire all of the labour needed for such activities. The amount of labour available to the household is its human capital. A livelihoods analysis by household member will contribute to wastewater research through improved understanding by gender, age and household characteristics of how much time is dedicated to each particular wastewater-related activity, how much wastewater-derived income is earned (or saved) and in which other types of wastewater and non-wastewater related activities the household is engaged.

A livelihoods approach specifically stresses the importance of studying the different access to resources within a household between men and women. The degree of involvement of each household member provides insight into the poverty dimensions of who would be the most vulnerable if changes in the quantity and quality of the resource occurred due to external factors. Some examples from case studies are, diversion to other, perhaps more powerful, interests in the event of the construction of a new treatment plant (see Silva-Ochoa and Scott on Guanajuato, Mexico, Chapter 13, this volume), the upstream diversion of large

[3] Toddy is a beverage tapped from a toddy palm tree that is often drunk fermented.

[4] If a household is at an early stage in its life cycle, most of the children are very young and cannot yet make economic contributions. If a household is at a late stage in its life cycle, many members will be too elderly to contribute economically and in some cultures the adult sons and/or daughters may already have set up their own households elsewhere.

amounts of wastewater by large landholders or other users depriving downstream users of sufficient water (Buechler, 2001), or the construction of a pipeline from the urban area to transport the wastewater to another river basin as is planned in Hyderabad.

Research must be conducted on the degree of involvement in fieldwork to determine individual and group risks to health. Wastewater irrigation and such activities as transplanting or weeding in flooded areas like paddy fields often require the closest and most prolonged contact with the wastewater. In many areas of the world, these tasks are affected by gender divisions of labour that make it culturally more acceptable, for example, for men in Latin America and most of South Asia to irrigate, and women to weed and transplant. These agricultural operations are practiced mainly by lower-income groups (farmers with few assets or labourers hired by farmers with more assets). To take the case of wastewater-irrigated paddy rice in the rural areas near Hyderabad, it is men who usually irrigate the rice and women who transplant and weed it. During all of these operations, the person must stand in the wastewater, increasing their risk of skin diseases and possibly other health problems, but for weeding and transplanting women are in the water for about 8 hours per day compared to 1 hour per day for the men, because for most of the time they are irrigating they do not stand in the water. In one year, therefore, with two paddy rice crops in wastewater-irrigated areas, women could be in the water for 100 days for 8 hours per day for a total of 800 hours whereas the number of hours for men is far less at about 240 days for about 1 hour per day or 240 hours. Women spend more time weeding wastewater-irrigated vegetable fields in urban and peri-urban Hyderabad than men (Buechler and Devi, 2002a), therefore their risk of helminth infections from contact with the soil may also be higher. So risks, are also likely to be gender-related. Class/caste issues play a role in risk since those from lower- income categories generally have more contact with the wastewater than richer social groups, who can afford to hire others to perform the work that requires the most contact with the wastewater.

Infrastructure at the micro-level

Infrastructure at the micro-level, similar to that at the meso-level, affects livelihoods. For example, health risks at the micro-level are influenced by the types of infrastructure available to a community to store and to channel the wastewater to the field. Retaining water in a pond could make it safer to use by reducing the number of helminth eggs and microorganisms such as *Escherichia coli* it contains through oxidation, radiation, and settling. Varying degrees of contact by irrigators with the soil and with the wastewater are necessary to channel the water to the field (e.g. watering cans versus earthen field channels), with greater contact meaning greater risk to irrigators.

Institutions and organisations at the local level

Participation and/or membership in organisations and institutions related to wastewater use at the micro-level (for example, at the level of the municipality, or the local level of the town, village, urban or peri-urban neighbourhood) may be based upon such affiliations as landholding and water-access status, and the overlapping affiliations of class, caste, religion, gender and ethnicity. For example, in Hyderabad, an urban farmers' association exists that is primarily composed of wastewater farmers who own land; in the peri-urban and rural areas water-user associations are composed of landed farmers with access to wastewater for irrigation; and caste groups in urban, peri-urban and rural wastewater-irrigated areas have their own organisations and meet in the caste community centre.

Similarly, at the local level a *de facto* situation exists in relation to rules and regulations governing water pollution and wastewater use. The interactions between user groups, industry and governmental agencies are both locally specific and dynamic in nature. In practice, the application of national-level or even state-level laws is renegotiated at the local level, but often not on a level playing field. Large industries and commercial establish-

ments are often able to dominate. This affects livelihoods in the area. An example of this is found in Patancheru, Andhra Pradesh, India, 20 km from Hyderabad city. Here industries were able to pressure the Government of Andhra Pradesh to create a pipeline to Hyderabad so that they are able to release industrial effluents into the sewage treatment plant (STP) there that is currently equipped only for primary treatment of domestic sewage which is subsequently released into a system of irrigation canals and into the Musi river. However, farmers' associations, environmental groups and citizen action groups in and near Hyderabad were able to apply pressure and challenge this Supreme Court decision forcing the Court to declare a Stay Order on the proposed pipeline. The pipeline is still under construction, however, and farmers fear that the effluents may be piped in even before the mandatory upgrade of the STP has been completed (Buechler, fieldwork 2003).

Conclusions

There is a critical need to utilise an SL approach for the study of wastewater. This approach must be actor-centred, can be multi-disciplinary, and should be oriented towards the study of change. A focus on actors involved in wastewater management at all levels generates knowledge that is tailored to the needs of the varied groups of people and institutions who use and manage wastewater and to the complex contexts in which wastewater use occurs. This will lead to solutions that are appropriate for the present with a view to preserving natural resources and income-generating activities based on those resources for future generations. Wastewater-dependent people have a rich knowledge base stemming from their daily experience in wastewater management and can provide information on where interventions might be necessary and on which types of interventions would address their particular problems. The livelihood security of these individual women, men and children and of their households is invariably linked to benefits derived from and problems related to wastewater dependence. The various assets (in the form of social, financial, natural, physical, human and political capital) that wastewater-dependent people have at their disposal are affected by social, economic, political and environmental factors.

For a complete understanding of issues related to wastewater use at a basin level, the macro-, meso- and micro-levels need to be studied from a multi-disciplinary perspective addressing socio-economic, health and technical issues. Macro-level analyses should include river basin issues focusing particularly on upstream and downstream tradeoffs.

Meso-level analyses need to focus on the wastewater delivery system from both technical and organisational perspectives to ensure that infrastructure will be viewed as a dynamic tool for livelihood creation and sustenance. Pollution control boards, metropolitan water and sanitation boards and irrigation departments may all play important but different roles than expected in waste and wastewater management. The *de jure* and *de facto* functioning of various actors with positions in governmental agencies responsible for wastewater management requires attention. What is legally sanctioned may be very different from the everyday practices of the actors within the organisations.

By highlighting users and their perceptions about changes in wastewater quality and quantity, micro-level analyses can lead to improved planning and management surrounding wastewater issues at the level of the nation, region, district, municipality, peri-urban area or village. The gender, caste, class, ethnic, religious and economic characteristics of the users in urban, peri-urban and rural areas affect the types of wastewater-related activities in which they engage. When studying the micro-level of the user, it is important to analyse the interconnections between users. There is a chain of economic beneficiaries from wastewater whose livelihoods depend indirectly and directly on it. Household-level analysis of the contributions of wastewater to livelihoods examines the effects of household composition and stage in the household life cycle on, for example, the contributions of each member to wastewater and non-wastewater dependent income-generating and income-saving activities.

Using a SL framework of analysis to study infrastructure use at the local level will reveal

that this infrastructure is altered according to the separate needs of the different users at distinct and localised areas. The infrastructure needs of the users will depend on the area's economic conditions, formal and informal educational facilities, and geophysical characteristics together with the hydrology and hydraulics of the wastewater system.

Institutions and organisations at the level of the village or neighbourhood shape the ways in which wastewater is managed through members active in these organisations. Organisations may be composed of members with similar socio-economic characteristics. Similar to those at higher levels, at the local level a *de jure* and *de facto* distinction exists in relation to rules and regulations governing water pollution and the use of wastewater.

Integrated analyses for action research are imperative when attempting to ensure the sustainability of livelihoods based on wastewater. A SL approach to data collection and analysis helps ensure the social acceptability, economic viability and technical feasibility of the recommendations derived from action research on wastewater. Long-term studies on particular wastewater use areas using the SL approach are also vitally important because the growing volumes of wastewater produced as cities grow often changes the location and expands farming activities. Long-term SL analyses will show the dynamism inherent in wastewater use for household sustenance.

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4 Health Guidelines for the Use of Wastewater in Agriculture: Developing Realistic Guidelines

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Abstract

The use of wastewater in agriculture – often untreated or inadequately treated – is occurring more frequently because of water scarcity and population growth. Often the poorest households rely on this resource for their livelihood and food security needs. However, there are negative health implications of this practice that need to be addressed. In 1989 the World Health Organization (WHO) developed guidelines for the safe use of wastewater in agriculture, which are currently being revised based on new data from epidemiological studies, quantitative microbial risk assessments and other relevant information. The revisions being developed are in accordance with the *Stockholm Framework* that provides a tool for managing health risks from all water-related microbial exposures. The *Stockholm Framework* encourages a flexible approach to setting guidelines, allowing countries to adapt the guidelines to their own social, cultural, economic, and environmental circumstances. It is important to recognise that in many situations where wastewater is used in agriculture, the effective treatment of such wastewater may not be available for many years. WHO guidelines must therefore be practical and offer feasible risk-management solutions that will minimise health threats and allow for the beneficial use of scarce resources. To achieve the greatest impact on health, guidelines should be implemented with such other health promoting measures as: health education, hygiene promotion, provision of adequate drinking water and sanitation, etc.

Introduction

The use of wastewater in agriculture is growing due to water scarcity, population growth, and urbanisation, which all lead to the generation of yet more wastewater in urban areas. Wastewater can be used to substitute for other better-quality water sources, especially in agriculture – the single largest user of freshwater and wastewater worldwide. However, the uncontrolled use of wastewater in agriculture has important health implications for produce consumers, farmers and their families, produce vendors, and communities in wastewater-irrigated areas. Negative health impacts from the use of untreated or inadequately treated wastewater have been documented in many studies. Less attention has been paid to the positive health impacts of the use of wastewater in agriculture that may result from improved

 Wastewater Use in Irrigated Agriculture
(eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

household food security, better nutrition, and increased household income.

Guidelines for the safe use of wastewater in agriculture need to maximise public health benefits while allowing for the beneficial use of scarce resources. Achieving this balance in the variety of situations that occur worldwide (especially in settings where there may be no wastewater treatment) can be difficult. Guidelines need to be adaptable to the local social, economic, and environmental conditions and should be co-implemented with such other health interventions as hygiene promotion, provision of adequate drinking water and sanitation, and other healthcare measures. The *Hyderabad Declaration on Wastewater Use in Agriculture* (Appendix 1, this volume) recognises these principles and recommends a holistic approach to the management of wastewater use in agriculture.

Following a major expert meeting in Stockholm Sweden in 1999, the International Water Association (IWA) on behalf of the World Health Organization (WHO) published *Water Quality: Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-related Infectious Disease*. This publication outlines a harmonised framework for the development of guidelines and standards for water-related microbiological hazards (Bartram *et al.*, 2001; Prüss and Havelaar, 2001). The suggested framework involves the assessment of health risks prior to setting health targets; defining basic control approaches, and evaluating the impact of these combined approaches on public health status (Fig. 4.1). The framework is flexible and allows countries to adjust the guidelines to local circumstances and compare the associated health risks with risks that may result from microbial exposures through drinking water or recreational/occupational water contact (Bartram *et al.*, 2001). It is important that health risks from the use of wastewater in agriculture be put into the context of the overall level of gastrointestinal disease within a given population. Future WHO water-related guidelines will be developed in accordance with this framework.

The regulation of water quality for irrigation is of international importance because trade in agricultural products across regions is growing and products grown with contaminated water may cause health effects at both the local and transboundary levels. Exports of

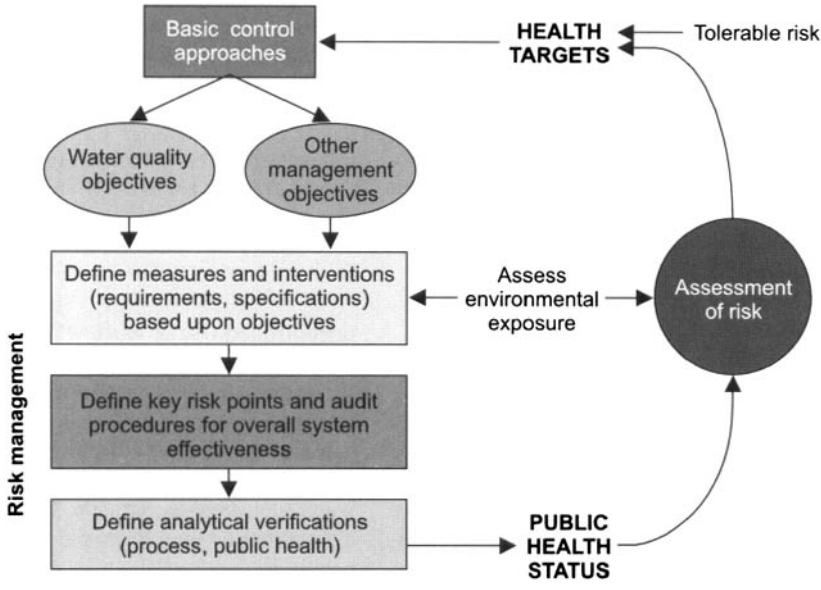

Fig. 4.1. Stockholm Framework for assessment of risk for water-related microbiological hazards (adapted from Bartram *et al.*, 2001).

contaminated fresh produce from different geographical regions can facilitate the spread of both known pathogens and strains with new virulence characteristics into areas where such pathogens are not normally found or have been absent for many years (Beuchat, 1998).

Effective guidelines for health protection should be: feasible to implement; adaptable to local social, economic, and environmental factors; and include the following elements:

- Evidence-based health risk assessment
- Guidance for managing risk (including options other than wastewater treatment)
- Strategies for guideline implementation (including progressive implementation where necessary).

This chapter provides an overview of the current status of wastewater use in agriculture, reviews the evidence on health impacts, and outlines management steps that can be implemented to reduce potential health impacts especially in low-resource settings.

Background

Worldwide, it is estimated that 18% of cropland is irrigated, producing 40% of all food (Gleick, 2000). A significant portion of irrigation water is wastewater. Hussain *et al.* (2001) report on estimates that at least 20 million ha in 50 countries are irrigated with raw or partially treated wastewater. Smit and Nasr (1992) estimated that one tenth or more of the world's population consumes foods produced on land irrigated with wastewater. Wastewater and excreta are also used in urban agriculture. A high proportion of the fresh vegetables sold in many cities, particularly in less-developed countries are grown in urban and peri-urban areas. For example, in Dakar, Senegal, more than 60% of the vegetables consumed in the city are grown in urban areas using a mixture of groundwater and untreated wastewater (see Faruqui *et al.*, Chapter 10, this volume).

In many developing countries, wastewater used for irrigation, is often inadequately treated. For example, WHO/UNICEF (2000) estimate the median percentage of wastewater treated by effective treatment plants to be 35% in Asia, 14% in Latin America, and the Caribbean, 90% in North America and 66% in Europe. Other figures are even lower: for example, Homsi (2000) estimates that only around 10% of all wastewater in developing countries receives treatment. Given these circumstances, WHO guidelines must include feasible strategies for maximising health protection when untreated wastewater is used in agriculture.

Evidence Base

Health effects

Previous WHO guidelines (see Table 4.1; WHO, 1989) were based on a number of available epidemiological studies, many of which were reviewed by Shuval *et al.* (1986). The evidence at that time suggested that the use of untreated wastewater in agriculture presented a high actual risk of transmitting intestinal nematodes and bacterial infections especially to produce consumers and farm workers; but that there was limited evidence that the health of people living near wastewater-irrigated fields was affected. There was less evidence for the transmission of viruses and no evidence for the transmission of parasitic protozoa to farm workers, consumers or nearby communities. The review of epidemiological evidence by Shuval *et al.* (1986) also indicated that irrigation with treated wastewater did not lead to excess intestinal nematode infections among field workers or consumers (WHO, 1989).

In 2002, Blumenthal and Peasey completed a critical review of epidemiological evidence on the health effects of wastewater and excreta use in agriculture for WHO. A sub-set of analytical epidemiological studies were selected that included the following features: well-defined exposure and disease, risk estimates calculated after allowance for confounding factors, statistical testing of associations between exposure and disease, and evidence of causality (where available). These were used as a basis for estimating threshold levels below which no excess infection in the exposed population could be expected. Further information on the risks of infection attributable to exposure, and in particular on the proportion of disease in the study population attributable

Table 4.1. Recommended revised microbiological guidelines for treated wastewater use in agriculture[a,b].

Category	Reuse conditions	Exposed group	Irrigation technique	Intestinal nematodes[c] (arithmetic mean number of eggs/l[d])	Faecal coliforms (geometric mean number/ 100 ml[e])	Wastewater treatment expected to achieve required microbiological quality
A	*Unrestricted irrigation*					Well-designed series of waste stabilisation ponds (WSP), sequential batch-fed wastewater storage and treatment reservoirs (WSTR) or equivalent treatment (e.g. conventional secondary treatment supplemented by either polishing ponds or filtration and disinfection)
	A1 Vegetable and salad crops eaten uncooked, sports fields, public parks[f]	Workers, consumers, public	Any	≤0.1 [≤1][g]	≤ 10^3	
B	*Restricted irrigation*					Retention in WSP series including one maturation pond or in sequential WSTR or equivalent treatment (e.g. conventional secondary treatment supplemented by either polishing ponds or filtration)
	Cereal crops, industrial crops, fodder crops, pasture and trees[h]	B1 Workers (but no children <15 years), nearby communities	(a) Spray/ sprinkler	≤ 1	≤ 10^5 [no standard]	
		B2 As B1	(b) Flood/ furrow	≤ 1	≤ 10^3 [no standard]	As for Category A
		B3 Workers including children <15 years, nearby communities	Any	≤0.1 [≤ 1] [no standard]	≤ 10^3	As for Category A
C	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Trickle, drip, or bubbler	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation.

Sources: Adapted from Blumenthal *et al.*, 2000a; WHO, 1989.

[a] Values in brackets are the 1989 guideline values.
[b] In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.
[c] *Ascaris* and *Trichuris* species and hookworms; the guideline is also intended to protect against risks from parasitic protozoa.
[d] During the irrigation season (if the wastewater is treated in WSP or WSTR which have been designed to achieve these egg numbers, then routine effluent quality monitoring is not required).
[e] During the irrigation season (faecal coliform counts should preferably be done weekly, but at least monthly).
[f] A more stringent guideline (≤ 200 faecal coliforms/100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[g] This guideline can be increased to ≤1 egg/l if (i) conditions are hot and dry and surface irrigation is not used, or (ii) if wastewater treatment is supplemented with antihelminthic chemotherapy campaigns in areas of wastewater re-use.
[h] In the case of fruit trees, irrigation should cease 2 weeks before fruit is picked and no fruit should be picked off the ground. Spray/sprinkler irrigation should not be used.

to exposure (and therefore potentially preventable through improvement in wastewater quality), was used to inform proposals on appropriate microbiological guidelines for wastewater reuse in agriculture. A summary of the results of this epidemiological review are presented in Table 4.2.

Wastewater is often a resource for the poor and in many cases the water and nutrients it contains can have important – yet largely uncharacterised – impacts on food security (Buechler and Devi, 2003). Improving nutrition, especially for children, is very important in maintaining the overall health of individuals and communities. Malnutrition is estimated to have a significant role in the deaths of 50% of all children in developing countries – 10.4 million children under the age of 5 die each year (Rice *et al.*, 2000; WHO, 2000). Malnutrition affects approximately 800 million people, or 20% of all people in the developing world (WHO, 2000). Malnutrition may also have long-term effects on the health and social development of a community, and leads to both stunted physical growth and impaired cognitive development (Berkman *et al.*, 2002).

Improving the living standards of the poor through developing irrigation (with wastewater or freshwater) can lead to better health, in some cases, even when irrigation leads to an increase in disease vectors (van der Hoek *et al.*, 2001a). For example, a study in Tanzania showed that a village where a rice irrigation scheme had been developed had more malaria vectors than a nearby savannah village but a lower level of malaria transmission (Ijumba, 1997).

Table 4.2. Summary of health risks associated with the use of wastewater in irrigation.

	Health threats		
Group exposed	Nematode infection	Bacteria/Viruses	Protozoa
Consumers	Significant risks of *Ascaris* infection for both adults and children with untreated wastewater; no excess risk when wastewater treated to <1 nematode egg/l except where conditions favour survival of eggs	Cholera, typhoid and shigellosis outbreaks reported from use of untreated wastewater; sero-positive responses for *Helicobacter pylori* (untreated); increase in non-specific diarrhoea when water quality exceeds 10^4 FC/100 ml	Evidence of parasitic protozoa found on wastewater-irrigated vegetable surfaces but no direct evidence of disease transmission
Farm workers and their families	Significant risks of *Ascaris* infection for both adults and children with contact with untreated wastewater; risks remain, especially for children when wastewater treated to <1 nematode egg/l; increased risk of hookworm infection to workers	Increased risk of diarrhoeal disease in young children with wastewater contact if water quality exceeds 10^4 FC/100ml; elevated risk of *Salmonella* infection in children exposed to untreated wastewater; elevated seroresponse to Norovirus in adults exposed to partially treated wastewater	Risk of *Giardia intestinalis* infection was insignificant for contact with both untreated and treated wastewater, Increased risk of amoebiasis observed from contact with untreated wastewater
Nearby communities	*Ascaris* transmission not studied for sprinkler irrigation but same as above for flood or furrow irrigation with heavy contact	Sprinkler irrigation with poor quality water 10^{6-8} TC/100 ml, and high aerosol exposure associated with increased rates of viral infection; use of partially treated water 10^{4-5} FC/100 ml or less in sprinkler irrigation not associated with increased viral infection rates	No data for transmission of protozoan infections during sprinkler irrigation with wastewater

Sources: Blumenthal and Peasey, 2002; Blumenthal *et al.*, 2000a; Armon *et al.*, 2002

The village with the irrigation scheme had more resources to buy food, children had a better nutritional status, and the villagers were more likely to buy and use mosquito nets (Ijumba, 1997). Similar results may also be applicable to the development of wastewater-use schemes in some countries.

Microbial guideline derivation

Worldwide many different microbial standards for wastewater use in agriculture have been developed. Most guidelines lay heavy emphasis on microbial standards, but it should be recognised that other strategies for managing health risks may also be effective. Based on an approach that used empirical epidemiological studies, microbiological studies of the transmission of pathogens, and quantitative microbial risk assessment (see Table 4.3), Blumenthal *et al.* (2000a) proposed revisions to the WHO microbiological guidelines for treated wastewater use in agriculture (Table 4.1). The main differences from the 1989 WHO guidelines are new recommendations for a faecal coliform (FC) value for restricted irrigation ($\leq 10^5$ FC/100 ml) and new FC and nematode egg limits in certain conditions when children are exposed.

Risk assessment

The health risk from pathogens in wastewater can be estimated by using a quantitative microbial risk assessment (see Table 4.3) based on data derived from the following evaluations:

- Hazard identification (HI)
- Exposure assessment (EA)
- Dose-response analysis (DRA)
- Risk characterisation (RC)

Quantitative microbial risk assessment (QMRA) provides a technique for estimating the risks from a specific pathogen associated with a specific exposure pathway. QMRA is a sensitive tool that can estimate risks that would be difficult to measure and therefore provides a useful supplement to epidemiological investigations that are less sensitive and more difficult to perform. However, QMRA is only as good as the data available and the assumptions made.

A number of QMRA have been performed for the use of wastewater in agriculture. Table 4.4 presents some information on the estimated health risks associated with different levels of indicator organisms (*Escherichia coli*) present in the wastewater. *Escherichia coli* is almost always found in human and animal faeces and thus indicates the presence of faecal contamination in water. The presence of *E. coli* in a water sample will often (but not always) mean that other excreta-related pathogens are also present. It is easier to measure *E. coli* concentrations and assume that this represents a group of similar pathogens than to measure concentrations of individual pathogens.

Tolerable Risk and Decision-making

A level of risk can be estimated for almost any exposure, in other words, there is no such thing as zero risk, only very low risks. Because a level of risk can always be estimated, it is important that a risk tolerable to society be defined. To facilitate the comparison of different health outcomes (e.g. diarrhoea compared to cancer) risks can be framed in terms of disability adjusted life years (DALYs) which are a measure of years lost due to premature death and/or disability caused by a disease (Prüss and Havelar, 2001).

For water-related exposures, WHO has determined that a disease burden of 1×10^{-6} DALYs per person per year (one 'microDALY') from a disease caused by either a chemical or infectious agent transmitted through drinking water is a tolerable risk (WHO, 2004). This level of health burden is equivalent to a mild illness (e.g. watery diarrhoea) with a low case-fatality rate (e.g. 1 in 100,000) at an approximate 1 in 1000 (10^{-3}) annual risk or 1 in 10 lifetime risk of disease in an individual (Havelaar and Melse, 2003; WHO, 1996, 2004). For exposure to a carcinogen, this level of disease burden is broadly equivalent to a 10^{-5} lifetime excess risk of renal cancer (1 excess case of cancer/100,000 individuals exposed to the chemical over a lifetime) (Havelaar and Melse, 2003). The third edition of the *WHO Guidelines for Drinking Water Quality* will use the approach described above to define tolerable risks (WHO, 2004).

Table 4.3. Types of evidence used to develop microbial guidelines.

Data source	General principles	Wastewater-specific concerns
Epidemiological studies	Evaluate the actual disease transmission due to a specific exposure, e.g., compare the level of disease in similar populations with different exposures, i.e. a population that uses wastes with an unexposed or control population that does not. The difference in disease levels may then be attributed to the practice of using wastes. Data from epidemiological studies are crucial for guideline derivation, but studies must be large enough to capture significant differences in levels of disease due to a specific exposure	Wastewater use studies focus on the transmission of excreta-related diseases (e.g. gastrointestinal illness, diarrhoea, helminth infections, parasitic protozoal infections and some viral infections). Risks to produce consumers, exposed communities and workers can be evaluated
Microbiological studies	Studies that identify pathogens in the environment and evaluate pathogen survival. Provide useful information concerning the presence or absence of pathogens	Evaluate pathogen presence and quantity in wastewater, conduct studies of pathogen survival in fields and on crops, and test wastewater-irrigated crop surfaces for pathogens
Quantitative microbial risk assessment (QMRA)	Used to complement other studies. Determines a theoretical risk of disease transmission given a specific exposure Is more sensitive than an epidemiological study but requires validated assumptions	
	Hazard identification (HI) Identify potential hazards e.g. pathogenic organisms and toxic chemicals and potential exposure routes to the hazard. Concentrations of excreta-related pathogens can be approximated by monitoring reference organisms such as *E. coli* that have similar characteristics to groups of pathogens	Identify excreta-related hazards. Determine if exposure routes exist e.g. through direct contact with wastewater, consumption of contaminated crops, inhalation of pathogen-containing aerosols, and consumption of animal products that have been exposed to the wastewater (e.g. beef tapeworm)
	Exposure assessment (EA) Estimates the quantities of pathogens to which a person (or animal) might be exposed via the different exposure routes	Based on evaluations of the quantities of pathogens in the wastewater, reductions in pathogens due to various treatment stages, pathogen transport to crops, and pathogen die-off in soil and on crops
	Dose-response analysis (DRA) The number of pathogens to cause infection/disease – determined from experimental studies using volunteers, depends on the virulence of the pathogen, the susceptibility of the population and immune status of the population	Helminths, protozoa, and viruses often have very low infectious doses e.g. 1–100. Bacteria have higher infectious doses e.g. 1,000–1,000,000
	Risk characterisation (RC) Combines the information from the EA and DRA to determine if a significant health risk due to the exposure is likely. The risk is compared to a defined level of tolerable risk	Irrigation with wastewater may result in a certain level of contamination, a probability of disease can be calculated based on the estimated numbers of pathogen in the food, the amount of food consumed, and the frequency that food is consumed. Risks can be estimated for each exposure route

Sources: Blumenthal and Peasey, 2002; Petterson and Ashbolt, 2003; Teunis *et al.*, 1996.

Tolerable risks also need to be put into the context of all exposures leading to disease. For example, Mead *et al.* (1999) estimated that the average person (including all age groups) in the USA suffers from 0.8 episodes of acute gastroenteritis (GI) (characterised by diarrhoea, vomiting or both) per year (i.e. an 8×10^{-1} annual GI risk). The incidence rates of GI among adults worldwide are generally within the same order of magnitude (Murray and Lopez, 1996), but children living in high-risk situations where poor hygiene, sanitation and water quality prevail have more frequent gastrointestinal illnesses. Kosek *et al.*, (2003) found that children under the age of 5 in developing countries experienced a median of 3.2 annual episodes of diarrhoea per child (an annual risk of 3.2×10^{0}).

Risks of viral infection and diarrhoeal disease associated with contact with wastewater of different qualities have been estimated by QMRA techniques (Table 4.4). Guidelines should take these levels of risk into account. For example, if the background GI incidence rate in adults in a given population is 0.8 episodes per year, then treating wastewater to ≤2.2 total coliforms/100 ml (see Table 4.4) will potentially only add an extra 10^{-7} annual episodes of viral diarrhoea to the background level, i.e. the background level will increase from 0.8 to 0.8000001. Such a small increase is impossible to detect and, in any case, contributes virtually nothing to the background level. This implies that it is not necessary to treat wastewater to such a high quality.

However, with the same background rate of GI in adults, use of untreated wastewater would add an additional 0.2–0.6 annual GI episodes that would have a substantial impact on the level of GI, increasing it from 0.8 to 0.99 or 1.39 – i.e. increases of 25% and 76%, respectively. Treating the wastewater to the WHO guideline level of 1000 FC/100ml would add an extra 10^{-4}–10^{-5} infections, increasing the level from 0.8 to 0.8001, or 0.80001 annual episodes, that again does not perceptibly change the background level. This emphasises that the background levels of disease should be taken into consideration when microbial guideline values are established. The costs incurred in reaching different levels of risk must also be considered. Achieving such very low levels of risk through more advanced wastewater treatment technologies substantially increases costs (Fattal Shuval, 1999).

The Stockholm Framework requires that the risk of gastrointestinal illness in a given population be considered in the context of total risk from all exposures (i.e. drinking water, recreational water contact, and contaminated food). This facilitates making risk-management decisions that address the greatest risks first. For example, it will have very little impact on the disease burden if the number of cases of salmonellosis attributed to the use of wastewater in irrigation is halved if 99% of the cases are transmitted in other ways, most notably through contaminated food (Bartram *et al.*, 2001).

It is important to note that water quality requirements for the use of wastewater in unrestricted irrigation are often stricter than surface water quality requirements for unrestricted irrigation. In many places surface water would not meet WHO FC guideline targets for

Table 4.4. Estimated risks from the use of untreated or treated wastewater in irrigation of viral infection per person per year for various concentrations of *E. coli*[a].

E. coli concentration/100 ml	Risk of viral infection[b]		Reference
10^{7} (i.e. untreated)	0.2–0.6	(I) CV	Fattal and Shuval, 1999
1000	$2–9 \times 10^{-5}$	(I) CV	Shuval *et al.*, 1997
≤2.2[c]	$1 \times 10^{-7} – 7 \times 10^{-9}$	(I) CV	Tanaka *et al.*, 1998
≤2.2[d]	$2 \times 10^{-8} – 4 \times 10^{-10}$	(I) WC	Tanaka *et al.*, 1998

[a] *E. coli* concentrations in wastewater do not necessarily correspond to viral concentrations in wastewater.

[b] Risks are based on either the consumption of irrigated raw vegetables (CV) or contact with the wastewater during/after irrigation (WC).

[c] Total coliforms in chlorinated secondary effluent used for unrestricted crop irrigation.

[d] Total coliforms in chlorinated tertiary effluent used for golf course irrigation.

unrestricted irrigation (UNEP, 1991; Mara and Cairncross, 1989). Thus in some cases, strict wastewater quality standards for irrigation will paradoxically encourage the use of more contaminated water for irrigation resulting in greater health risks. For example, in irrigated areas near Santiago, Chile, 60% of the river water used for irrigation contained in excess of 10,000 FC/100 ml (ten times the recommended WHO standard) (FAO, 1993). Additionally, the United States Environmental Protection Agency (USEPA) recommends a standard for irrigation with treated wastewater of ≤2.2 total coliforms/100 ml, but when surface waters are used for irrigation a standard of ≤1000 FC/100 ml is required (USEPA, 1973). However, a percentage of FC in surface waters may not originate from sewage effluents or waste discharges, especially in tropical/sub-tropical regions, and this may have significant implications in terms of human health risk assessment (WHO, 1996).

In some places where freshwater is scarce people often drink water that is of a quality that does not meet drinking water standards, and would not meet strict standards (e.g. California Title 22 standards) for unrestricted irrigation. For example, in some areas in the southern Punjab, Pakistan, groundwater supplies are too brackish to drink, so people rely on irrigation water for their drinking water supplies. In one study, 58% of the water from the village reservoirs contained >100 *E. coli*/100 ml (van der Hoek *et al.*, 2001b). In these circumstances it would be highly inappropriate to expect that wastewater be treated to a higher quality than drinking water. Clearly, as the Stockholm Framework suggests, interventions that would yield higher health benefits should be given more priority.

Water quality guidelines need to be adapted to the social, economic, and environmental conditions of each country. When countries with high levels of excreta-related disease background levels and inadequate resources for wastewater treatment adopt overly strict water quality standards for use in agriculture, it may lead to a lower level of health protection because, in these circumstances, the standards may not significantly change the background level of disease and/or may be viewed as unachievable and thus ignored entirely.

Chemical Guidelines

In many countries, industrial wastewater is often mixed with the municipal wastewater used for irrigation. Industrial wastes may contain toxic organic and inorganic chemicals that can be taken up by the crops. The health risks associated with chemicals found in wastewater and sludge may need to be given more attention, particularly as industrialisation increases in developing countries. To minimise adverse health and environmental effects from toxic substances, industrial wastes should be adequately pre-treated to remove these chemicals, or should be treated separately from municipal wastewater and excreta.

It is difficult to assess the health impacts from toxic chemicals in wastewater used for irrigation because of the difficulty in associating chronic exposure to chemicals and chemical mixtures to diseases with long latency periods. However, in some parts of China, the use of heavily contaminated industrial wastewater for irrigation is thought to be associated with health problems. For example, in these areas a 36% increase in hepatomegaly (enlarged liver), and a 100% increase in both cancer and congenital malformation rates were observed compared to those problems in control areas where industrial wastewater was not used for irrigation (Yuan, 1993). Heavy metals in the wastewater can also pose a health risk, e.g. in Japan, China and Taiwan rice accumulated high concentrations of cadmium (and other heavy metals) when it was grown in soils contaminated with irrigation water containing substantial industrial discharges (Chen, 1992). In Japan, Itai-itai disease – a bone and kidney disorder – associated with chronic cadmium poisoning, occurred in areas where rice paddies were irrigated with water from the contaminated Jinzu river (WHO, 1992).

WHO is currently developing standards for a selection of harmful chemicals that might be found in wastewater. In many situations the safety of the wastewater for use in irrigation will need to be determined on a case-by-case basis, depending on the type of chemicals suspected to be present. Chemical analysis of such wastewater may be necessary. Chemical guideline values will be presented in the revised guidelines.

Strategies for Managing Health Risk

The protection of public health can best be achieved by using a 'multiple barrier' approach that interrupts the flow of pathogens from the environment (wastewater, crops, soil etc.) to people. Human pathogens in the fields do not necessarily represent a health risk if other suitable health protection measures can be taken. These measures may prevent pathogens from reaching the worker or the crop or, by selection of appropriate crops (e.g. cotton), may prevent pathogens on the crop from affecting the consumer (Mara and Cairncross, 1989). The measures available for health protection can thus be grouped into five main categories:

- Waste treatment
- Crop restriction
- Irrigation technique
- Human exposure control
- Chemotherapy and vaccination.

It will often be desirable to use a combination of several methods. For example, crop restriction may be sufficient to protect consumers, but will need to be supplemented by additional measures to protect agricultural workers. Sometimes partial treatment to a less-demanding standard may be sufficient if combined with other measures. The feasibility and efficacy of any combination will depend on many factors that must be carefully considered before any option is put into practice (Mara and Cairncross, 1989). These factors will include the following:

- Availability of resources (labour, funds, land)
- Existing social and agricultural practices
- Market demand for wastewater-irrigated products
- Existing patterns of excreta-related disease.

For example, if sufficient funds and/or sufficient land are not available for wastewater treatment, some of the other three types of health protection measure will be needed.

Treatment

When municipal or domestic wastewater is used in agriculture, the removal or inactivation of excreted pathogens is the principal objective of wastewater treatment. Conventional wastewater treatment options (primary and secondary treatments), as applied in developed countries, have traditionally focused on the removal of environmental pollutants [e.g. suspended solids, or biological oxygen demanding (BOD) substances] and not on pathogens. Many of these processes may be difficult and costly to operate properly in developing-country situations due to their high energy, skilled labour, infrastructure and maintenance requirements (Carr and Strauss, 2001). In some cases, tertiary treatment (e.g. filtration and/or disinfection) will be required to reduce the concentrations of pathogens in the effluents to WHO-recommended microbial guideline values. In some situations, the quality of primary or secondary treated effluents could be improved by retaining them for 5 days in a single polishing (maturation) pond to reduce the risk of disease transmission (Mara and Cairncross, 1989).

There is a need for research and development work to improve the helminth egg removal efficacy of conventional systems to meet microbial standards. Such processes as lime treatment, chemically enhanced primary treatment (CEPT), upward-flow anaerobic sludge blanket, sand filtration, and storage in compartmentalised reservoirs deserve further study (Mara and Cairncross, 1989). Parr *et al.* (2000) present a brief overview of some wastewater treatment options that might be suitable for developing countries.

CEPT is a treatment technique that uses specific chemicals (e.g. ferric chloride plus an anionic polymer) to facilitate particle coagulation and flocculation. Improving these processes increases the removal of suspended solids, BOD and intestinal nematode eggs (Morrissey and Harleman, 1992; Harleman and Murcott, 2001). Studies in Mexico City showed that CEPT was capable of producing effluents with 2–5 nematode eggs/l. When CEPT effluents were filtered through polishing, sand filters effluents with <1 nematode egg/l were produced at significantly lower cost than in a conventional secondary treatment system (primary plus activated sludge) (Harleman and Murcott, 2001).

Waste stabilisation ponds (WSP) have been used successfully in many situations for treating wastewater. When designed and operated properly, WSP are highly effective in removing pathogens and can be operated at low cost where inexpensive land is available. Ponds for

FC and helminth removal can designed using specific equations (Mara, 1997; Ayres *et al.*, 1992), examples of their use are given by Mara in Blumenthal *et al.* (2000b). However, WSP should be designed, operated and maintained in such a way as to prevent disease vectors from breeding in them.

Where effective treatment is not available, it may be possible to consider other options that improve microbial water quality, such as storage reservoirs that partially treat wastewater through simple sedimentation. For example, in Mexico, irrigation with untreated or partially treated wastewater was estimated to be directly responsible for 80% of all *Ascaris* infections and 30% of diarrhoeal disease in farm workers and their families, but, when wastewater was retained in a series of reservoirs there was minimal risk of either *Ascaris* infection or diarrhoeal disease (Cifuentes *et al.*, 2000). The use of reservoirs has the added advantage that wastewater can be stored for use in the dry season – the time of peak irrigation demand.

Crop restriction

Crop restriction can be used to protect the health of consumers when water of sufficient quality is not available for unrestricted irrigation. For example, water of poorer quality can be used to irrigate such non-vegetable crops as cotton, or crops that will be cooked before consumption (e.g. potatoes).

Crop restriction does not, however, provide protection to farm workers and their families where low-quality effluents are used in irrigation or where wastewater is used indirectly, i.e. through contaminated surface water (Blumenthal *et al.*, 2000b). Crop restriction is therefore not an adequate single control measure, but should be considered as part of an integrated system of control. To provide protection for both workers and for the consumers, it should be complemented by such other measures as partial waste treatment, controlled application of wastes, or human exposure control (Mara and Cairncross, 1989).

Crop restriction is feasible and is facilitated in several circumstances including the following (Mara and Cairncross, 1989):

- Where a law-abiding society or strong law enforcement exists
- Where a public body controls allocation of the wastes, and has the legal authority to require that crop restrictions be followed
- Where an irrigation project has strong central management
- Where there is adequate demand for the crops allowed under crop restriction, and where they fetch a reasonable price
- Where there is little market pressure in favour of excluded crops.

Crop restriction has been used effectively in Mexico, Peru and Chile (Blumenthal *et al.*, 2000b). In Chile when implemented with a general hygiene education programme the use of crop restriction reduced the transmission of cholera from the consumption of raw vegetables by 90% (Monreal, 1993).

Waste application methods

The choice of wastewater application method can have impact on the health protection of farm workers, consumers, and nearby communities. Spray/sprinkler irrigation has the highest potential to spread contamination on crop surfaces and affect nearby communities. Bacteria and viruses (but not intestinal nematodes) can be transmitted through aerosols to nearby communities. Where spray/sprinkler irrigation is used with wastewater it may be necessary to set up a buffer zone, e.g. 50–100 m from houses and roads, to prevent health impacts on local communities (Mara and Cairncross, 1989).

Farm workers and their families are at the highest risk when furrow or flood irrigation techniques are used. This is especially true when protective clothing is not worn and earth is moved by hand (Blumenthal *et al.*, 2000b).

Localised irrigation techniques, e.g. bubbler, drip, trickle offer farm workers the most health protection because they apply wastewater directly to the plants. Although these techniques are generally the most expensive to implement, drip irrigation has recently been adopted by some farmers in Cape Verde and India (FAO, 2001; Kay, 2001).

Vaz da Costa Vargas *et al.* (1996) demonstrated that stopping irrigation 1–2 weeks before harvest can effectively reduce crop contamination. However, this is likely to be difficult to implement in unregulated circumstances because many vegetables (especially lettuce or other leafy vegetables) need watering up to the point of harvest to increase their market value. This technique may be possible for some fodder crops that do not have to be harvested at the peak of their freshness (Blumenthal *et al.*, 2000b).

Human exposure control

The following four groups of people can be identified as being at potential risk from the agricultural use of wastewater:

- Agricultural field workers and their families
- Crop handlers
- Consumers (of crops, meat and milk)
- Those living near affected fields.

Agricultural field workers are at high potential – and often actual – risk, especially from parasitic infections. Exposure to hookworm infection can be reduced, even eliminated, by the use of less-contaminating irrigation methods (see above) and by the use of appropriate protective clothing, i.e. shoes for field workers and gloves for crop handlers. Rigorous health education programmes are needed (Blumenthal *et al.*, 2000b; Mara and Cairncross, 1989). Field workers should be provided with adequate water for drinking and hygiene purposes, in order to avoid the consumption of, and any contact with, wastewater. Similarly, safe water should be provided at markets for washing and 'freshening' produce. Consumers should cook vegetables and meat, boil milk, and practise good personal and domestic hygiene measures to protect their health.

Health education campaigns that focus on improving personal and domestic hygiene should target produce consumers, farm workers, produce handlers and vendors. Hand washing with soap should be emphasised. It may be possible to link health education and hygiene promotion to agricultural extension activities or other health programmes, e.g. immunisation (Blumenthal *et al.*, 2000b).

Chemotherapy and vaccination

Immunisation against helminthic infections and most diarrhoeal diseases is currently not feasible. However, for highly exposed groups, immunisation against typhoid and hepatitis A may be worth considering.

Additional protection can be provided if adequate medical facilities to treat diarrhoeal diseases, are available and by regular chemotherapy. This might include chemotherapeutic control of intense nematode infections in children and control of anaemia in both children and adults, especially women and post-menarche girls. Chemotherapy must be reapplied at regular intervals to be effective. The frequency required to keep worm burdens at a low level (e.g. as low as those in the rest of the population) depends on the intensity of the transmission, but treatment may be required 2–3 times a year for children living in endemic areas (Montresor *et al.*, 2002; Mara and Cairncross, 1989). Albonico *et al.* (1995) found that re-infection with helminths could return to pre-treatment levels within 6 months of a mass chemotherapy campaign if the prevailing conditions did not change.

Chemotherapy and immunisation cannot normally be considered adequate strategies to protect farm workers and their families exposed to raw wastewater or excreta. However, where such workers are organised within structured situations, such as on government or company farms, these treatments could be beneficial as palliative measures, pending improvement in the quality of the wastes used, or the adoption of other control measures, e.g. protective clothing (Mara and Cairncross, 1989).

Guideline Implementation

The scarcity of surface and groundwater in many countries has led, or is leading to the development of national plans for the rational allocation, utilisation and protection of available water resources. The objective of such plans is to ensure, as far as is practically possible, the maximum economic yield from the use of an increasingly scarce resource. Human wastes are relevant to these national

water plans as they can alter the physico-chemical and microbiological quality of water, and thus place restrictions on its use. The incorporation of protocols for waste use planning into national water plans is important, especially when water is scarce, not only to protect water quality but also to minimise treatment costs, to safeguard public health, and to obtain the maximum possible agricultural benefit from the nutrients and organic matter contained in the wastes (Mara and Cairncross, 1989).

Human wastes are already used for crop production in many countries, mostly informally and without official recognition by the health authorities. The *Hyderabad Declaration on Wastewater Use in Agriculture* (Appendix 1, this volume) recognises this reality. Where the practice is traditional or has arisen spontaneously, untreated or insufficiently treated wastes are commonly used. Experience in many countries has shown that simply to ban the practice is not likely to have much effect, if any, on its prevalence or on the level of public health risk involved. On the contrary, banning the practice is unlikely to stop it, but may make it more difficult to supervise and control, and may also interfere with disease surveillance and health care among those most exposed to the risk of infection. A more promising approach is to provide support to improve existing use practices, not only to maximise health protection, but also to increase productivity, as the major stakeholders are usually relatively poor farmers and consumers (Mara and Cairncross, 1989).

Additional legal controls will often be required, but, it is easier to make regulations than to enforce them. In drafting new regulations (or in choosing which existing ones to enforce) it is important to plan for the institutions, staff and resources necessary to ensure they are followed. Perhaps even more important is to ensure that the regulations are realistic and achievable in the context in which they are to be applied. It will often be advantageous to adopt a gradual approach, or to test a new set of regulations by persuading a local administration to pass them as by-laws before they are extended to the rest of the country (Mara and Cairncross, 1989). Some of the problems countries encounter when setting up and implementing standards have been reviewed by von Sperling and Fattal (2001).

Measures to protect public health are particularly difficult to implement when there are many individual sources or owners of the waste, whether these are individual septic tank overflows or farmers with riparian rights to pump from a river so polluted that it comprises only slightly diluted wastewater. If the wastewater can be brought under unified control by: installing a sewerage system, establishing a treatment plant (or plants), or diverting the wastewater from the river to a treatment works, this will give the controlling authority much greater power to influence the ways in which the wastewater is subsequently used, and thus to maximise health protection (Mara and Cairncross, 1989).

Implementation of the *WHO Guidelines for the Safe Use of Wastewater in Agriculture and Aquaculture* (WHO, 1989) will be of maximum benefit in protecting public health when they are integrated into a comprehensive public health programme that includes other sanitary measures including education and outreach that aim to change personal and domestic hygiene behaviour. For example, if the guidelines are followed in the field but produce is 'freshened' with contaminated water in the market, some of the potential health gains are likely to be erased.

Steps that will facilitate developing a guideline implementation plan are presented below. A sample action plan for incremental adoption of WHO guidelines is presented in Box 4.1. Further discussion of stepwise guideline implementation can be found in von Sperling and Fattal (2001).

Guideline implementation plan

1. Design and conduct a survey of wastewater and excreta use practices throughout the country or in specific districts. The survey could contain questions concerning:
   - The availability and types of wastewater treatment available
   - The types of crops grown in the area (whether they are eaten cooked or raw)
   - Techniques for wastewater and excreta application, e.g. bucket, furrow, sprinkler, other
   - An assessment of human exposure to wastewater and excreta during agricul-

Box 4.1. Sample action plan for incremental adoption of WHO guidelines[a]

Strengthen local capacity
Assemble a team of health and agricultural outreach workers who can work with farmers and villagers to improve health and agricultural practices and develop feasible crop restriction strategies and other interventions as necessary.

Health and hygiene education
Expand existing hygiene and sanitation outreach programmes to include information on potential health effects of wastewater use; educate farmers, produce vendors and consumers about food safety and hygiene.

Crop restriction
Work with farmers to develop feasible and health protective crop restrictions, especially in the areas of highest risk (e.g. where undiluted raw wastewater is used).

Waste application
Determine the safety level of current practices. As resources/technologies permit, shift to safer wastewater/excreta application practices where there is less human contact (e.g. drip and bubbler irrigation).

Human exposure control
Expand hygiene and health education programmes in affected communities. Require protective clothing at larger wastewater/excreta use projects and where feasible. Provide clean water at markets for 'freshening produce'. Inspect general hygiene at food markets.

Treatment
Introduce or upgrade treatment at strategic locations, phase in over a period of time (e.g. 10–15 years).

Examples

***First stage of treatment*:** natural purification processes (e.g. abstraction suitable distance downstream from discharge); irrigation storage reservoirs designed for pathogen removal, waste stabilisation ponds, primary treatment plus additional treatment (e.g. storage reservoir, chemically enhanced coagulation, coagulation + rapid sand filtration).

***Second stage of treatment*:** waste stabilisation ponds, conventional secondary treatment (e.g. activated sludge, trickling filter, etc.), aeration ponds, etc.

Third stage of treatment: waste stabilisation ponds, conventional secondary treatment + storage reservoir or disinfection, advanced processes (e.g. membrane filtration).

Microbial wastewater quality standards
Phase in WHO microbial wastewater quality standards over suitable period of time according to treatment capabilities. For example, the initial standards may be set at $\leq 10^5$ FC/100 ml and ≤ 5 viable intestinal nematode eggs/l for unrestricted irrigation (and/or with specific crop restrictions). As resources become available to build treatment facilities the standard could be tightened to $\leq 10^4$ FC/100 ml and ≤ 1 viable intestinal nematode egg/l, and eventually to the current recommendations ($\leq 10^3$ FC/100 ml and ≤ 1 viable intestinal nematode egg/l).

Other health interventions
Initiate or expand vaccination campaigns in affected areas, e.g. typhoid, hepatitis A. Complement hygiene and sanitation programmes with periodic antihelminthic drug campaigns (this works well where antihelminthic drugs are widely available at low cost and where wastewater and excreta use is limited to distinct areas in a country, e.g. Pakistan (Feenstra *et al.*, 2000). Mass antihelminthic drug campaigns against intestinal nematode infection may need to be considered at least once per year in areas where 50–70% of the school-aged children are infected with soil-transmitted helminthic infections. Where the prevalence of these infections exceeds 70% in school-aged children and more than 10% of the individuals are moderately or heavily infected, then children should be treated 2–3 times a year (Montresor *et al.*, 2002).

Industrial effluents
Initial efforts should be made to identify sources of industrial discharges. Phase in an approach that first requires large polluters to clean up their wastes or divert them from the municipal waste stream and eventually requires all of the industrial discharges to be treated separately.

[a] For more discussion on progressive guideline implementation see von Sperling and Fattal (2001).

tural practices, e.g. do fieldworkers wear protective clothing? do they practice good hygiene?

- Evaluation/prioritisation of health risks in the context of the national burden of disease, associated with the use of wastewater and excreta in agriculture.

  Quantitative: scientific studies of disease, review of clinical data, outbreak information, prevalence data, etc.

  Qualitative: interviews with health staff (doctors, nurses, pharmacists), farmers, families, community workers, teachers, etc.

3. National or district-level workshops to formulate appropriate (realistic) strategies for mitigating health impacts that include relevant stakeholders, e.g. farmers.
4. Develop national or other action plan/policy for the safe use of wastewater and excreta in agriculture.
5. Strengthen institutional capacities – designate responsible authority(-ies) to monitor and enforce safe wastewater and excreta use practices.
6. Review and revise national plan/policy as needed.

Conclusions

Developing realistic guidelines for using wastewater in agriculture involves the establishment of appropriate health-based targets prior to defining appropriate risk-management strategies. Establishing appropriate health-based targets primarily involves an assessment of the risks associated with wastewater use in agriculture, using evidence from available studies of epidemiological and microbiological risks, and risk-assessment studies. Considerations of what is an acceptable or tolerable risk are then necessary; these may involve the use of internationally derived estimates of tolerable risk, but these need to be put into the context of actual disease rates in a population related to all the exposures that lead to that disease, including other water- and sanitation-related exposures together with food-related exposure. Positive health impacts resulting from increased food security, improved nutrition, and additional household income should also be considered. Individual countries may therefore set different health targets, based on their own contexts.

Strategies for managing health risks to achieve the health targets include wastewater treatment to achieve appropriate microbiological quality guidelines, crop restriction, waste application methods, control of human exposure, chemotherapy, and vaccination. Phased implementation of the WHO microbial water quality standards may be necessary as treatment is gradually introduced and improved over a period of time, e.g. 1–15 years. For optimal public health effect, the guidelines should be co-implemented with such other health interventions as hygiene promotion, provision of adequate drinking water and sanitation, and other healthcare measures.

Note: The opinions expressed in this chapter are those of the authors and do not necessarily reflect the views or policies of WHO.

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5 A Fresh Look at Microbial Guidelines for Wastewater Irrigation in Agriculture: A Risk-assessment and Cost-effectiveness Approach

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Abstract

This study aimed to develop a risk-assessment/cost-effectiveness approach, to compare the risks of irrigating with wastewater treated to meet various recommended microbial guidelines – World Health Organization (WHO) versus United States Environmental Protection Agency (USEPA) – for unrestricted use in agriculture with the risk of irrigating with untreated wastewater. According to the authors' estimates, the annual risk of contracting infectious diseases including typhoid fever, rotavirus infection, cholera and hepatitis A from eating raw vegetables irrigated with untreated wastewater is in the range of 1.5×10^{-1} to 5×10^{-2}, or 5–15% of consumers eating such vegetables will develop a case of disease compared to 10^{-6} (0.0001%) of those eating vegetables irrigated with treated wastewater effluent that meets the WHO guideline of 1000 faecal coliforms (FC)/100 ml. The USEPA considers a 10^{-4} (0.01%) annual risk of becoming ill with an infectious disease acceptable for drinking water. Cost-effectiveness analysis shows that, on average, in a city with a population of one million, the prevention of a single case (out of 61 cases/year) of the four diseases: hepatitis A, rotavirus infection, cholera and typhoid according to WHO guidelines versus USEPA guidelines would entail an extra annual expenditure of wastewater treatment of US$450,000/case. It is questionable if this is a cost-effective or reasonable public health expenditure. The authors estimate that if every one of a million people ate raw vegetables irrigated with untreated wastewater, there would be a 1 in 10 annual risk (100,000 cases/year) of contracting one of these four diseases. Thus, in the authors' view irrigating vegetables eaten with raw untreated wastewater presents an unreasonably high health risk. However, treatment to meet WHO guidelines would cost US$125/case prevented. This appears to be reasonably cost-effective, but, is a question that must be decided upon by each community. Evaluating health risks by disability adjusted life years (DALY) is also considered.

Introduction

This study aimed to further develop a risk-assessment approach based on a mathematical model and experimental data, in order to conduct a comparative risk analysis of the various recommended wastewater irrigation microbial health guidelines for unrestricted irrigation of vegetables normally eaten raw (uncooked) based on the initial study by Shuval *et al.*, 1997. The guidelines evaluated were those recommended by WHO (1989) and USEPA/USAID

 Wastewater Use in Irrigated Agriculture
(eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

in 1992. Consideration was also given to the implications of irrigating such crops with untreated (raw) wastewater as discussed in other chapters of this volume.

Regulations to protect the health of people who consume crops irrigated by wastewater were initiated by the California State Board of Health. In 1933 they established the first microbial effluent standard that was equivalent to the one required for drinking water, which was then set at a most probable number (MPN) of 2.2 faecal coliforms (FC)/100 ml (Ongerth and Jopling, 1977). However, this standard was difficult to achieve even in developed countries, and was not feasible for most developing countries. In fact, hundreds of cities in the developing world could not afford to meet the very rigorous standards that they had innocently copied from the United States, and, thus, did not build any appropriate wastewater treatment plants.

In 1982 the World Bank and the World Health Organization embarked on a broad-spectrum, multi-institutional scientific study involving three independent teams of scientists to review the available epidemiological and technological evidence on health risks associated with wastewater irrigation (Shuval *et al.*, 1986; Feachem *et al.*, 1983; Struass and Blumenthal, 1989). These studies resulted in the publication in 1989, World Health Organization (WHO) *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture.* Based on the new epidemiological and technological evidence, the guidelines recommended a mean of 1,000 FC/100 ml and less than one helminth egg per litre of effluent, for the wastewater irrigation of vegetables eaten raw. The new guidelines have become widely accepted by international agencies including the Food and Agriculture Organization of the United Nations (FAO), United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP) and the World Bank and have been adopted by French health authorities and the governments of a number of developing, and developed countries.

In 1992 USEPA together with USAID published their own guidelines for water reuse. These were primarily intended for use within the USA, but were also developed so that they could be used as guidelines by USAID missions working in developing countries. These new guidelines for the irrigation of crops eaten raw are even stricter than the original California standards and call for no (zero) detectable FC/100 ml, biochemical oxygen demand (BOD) of 10 mg/l or less, turbidity of 2 nephalometric turbidity units (NTU) or less and chlorine residual of 1 mg/l. In addition, the guidelines stipulate rigorous engineering requirements for biological treatment, sand filtration, chemical disinfection and various fail-safe redundancies and back-up equipment facilities. The standard of zero detectable FC/100 ml had become the current American drinking water standard, so that once again United States thinking was apparently based on a zero indicator organisms or 'no risk' concept, regardless of its technical feasibility and cost-effectiveness for other parts of the world.

Risk-assessment Model

The risk-assessment model developed by Haas *et al.* (1993) for estimating the risk of infection and disease from ingesting microorganisms in drinking water, was used in this study. However, certain modifications were required to fit the risk of infection associated with eating vegetables irrigated with wastewater of variable microbial quality (Shuval *et al.*, 1997). The probability of infection (P_I) from ingesting pathogens in water, according to Haas *et al.* (1993), is presented in Equation 1:

$$P_I = 1-[1+N/N_{50}\,(2^{1/\alpha}-1)]^{-\alpha} \qquad (1)$$

P_I = The risk of infection by ingesting pathogens in drinking water
N = The number of pathogens ingested
N_{50} = The number of pathogens that will infect 50% of the exposed population
α = A slope parameter; the ratio between N_{50} and P_I

Since not every person infected by the ingestion of pathogens becomes ill, an independent estimate is made of P_D – the probability of contracting a disease (see Equation 2):

$$P_D = P_{D:I} \times P_I \qquad (2)$$

P_D = The risk of an infected person becoming ill
$P_{D:I}$ = The probability of an infected person developing clinical disease

The Number of Pathogens Ingested

Based on laboratory determinations, the authors found that the amount of wastewater of varying microbial quality that would cling to the external surface of wastewater-irrigated cucumbers is 0.36 ml/100 g (one large cucumber) and 10.8 ml/100 g of long-leaf lettuce (about 3 lettuce leaves) (Shuval *et al.*, 1997). Based on these measurements, the amount of indicator organisms that might remain on the vegetables if irrigated with untreated wastewater (with 10^7 FC/100 ml) and with wastewater meeting WHO guidelines (10^3 FC/100 ml) were estimated. According to Schwartzbrod (1995), the ratio of enteric virus : FC is 1:10^5. For the preliminary risk estimate, it was assumed that all of the enteric viruses are a single pathogen species, such as the viruses of hepatitis A or poliomyelitis, therefore certain assumptions as to median infectious dose and infection to morbidity ratios need to be made.

It was also assumed that under actual field conditions there would be a certain degree of indicator and pathogen die-away and/or removal from the wastewater source until final ingestion by the consumer at home. Factors affecting die-away include: settling, adsorption, desiccation, biological competition, UV irradiation from sunlight, and a degree of removal and/or inactivation as a result of washing the vegetables at home. A number of studies have indicated that there is a rapid die-away or removal of both bacterial indicator organisms and of pathogenic bacteria and viruses in wastewater-irrigated soil and on crops of as much as 5-log in 2 days under field conditions (Bergner-Rabinowitz, 1956; Rudolfs *et al.*, 1951; Sadovski *et al.*, 1978; Armon *et al.*, 1995). Asano and Sakaji (1990) determined virus die-away under field conditions of wastewater reuse, and found that within 2 weeks total virus inactivation reaches about 99.99%, while in 3 days there is a 90% reduction in virus concentration. Even superficial washing of vegetables at home can remove an additional 99–99.9% of the viral contamination. Schwartzbrod (1995) estimated that there would be as much as a 6-log reduction of virus concentration between irrigation with wastewater and consumption of the crops if the total elapsed time reached 3 weeks. To be on the conservative side, it was estimated that the total entero-viruses and bacteria inactivation and/or removal from the wastewater source until ingestion, results in a reduction in pathogenic microorganism concentration by 3-log, or 99.9%, although a 99.99% loss is not unreasonable and might occur in most cases. It can be assumed that this also applies in the case of irrigation with untreated wastewater.

Estimates of Risk of Infection and Disease

Based on the above tests and assumptions, the number of pathogens ingested by a person who eats a 100-g cucumber or 100 g (three leaves) of long-leaf lettuce irrigated with wastewater of various quality was estimated. Four pathogens were selected: two enteric viruses (rotavirus and hepatitis A) and two enteric bacteria (*Vibrio cholera* and *Salmonella typhi*), with epidemiological evidence indicating the possibility of their being environmentally transmitted and/or waterborne (Schwartzbrod, 1995). It was assumed that a minimal infectious dose for 50% of the exposed population to become infected (N_{50}) ranges between 5.6 and 10^4 depending on the pathogen (see Tables 5.1a and b). While the authors are fully aware that the ratio of infection to clinical disease is often as low as 100:1, they assumed conservatively for this study, that 50% of those infected will succumb to clinical disease ($P_{D:I} = 0.5$). They also assumed, based on vegetable consumption patterns in Israel, that on an annual basis a person would consume 100 g of lettuce or cucumbers/day for a total of 150 days. The risk was calculated, using both a severe α value of 0.2, rather than 0.5 (Tables 5.1 and 5.2). However, if $\alpha = 0.5$ were used it would decrease the risk by about 1-log.

First, as a positive control test of the model the risk of infection and disease from consuming vegetables irrigated with untreated wastewater with an estimated initial FC level of 10^7/100 ml. Assuming a 3-log die-away prior to consumption of the vegetables, it was estimated that under such conditions a 100-g cucumber or 100 g of lettuce irrigated with untreated wastewater would have a final FC level of 30 to 10^3. Based on this FC level and a virus:FC ratio of 1:10^5, there is a probability that when irrigated with untreated wastewater, 3 out of 10,000

Table 5.1. The risk of infection and disease caused by various pathogens from:

a. Eating 100 g (3 leaves) of long-leaf lettuce irrigated with untreated wastewater once or for 150 days/year.

		One-time risk		Annual risk	
Pathogens	$(N_{50})^a$	P_I	P_D	P_I	P_D
Rotavirus[b]	5.6	2.7×10^{-3}	1.3×10^{-3}	4.0×10^{-1}	1.0×10^{-1}
Hepatitis A virus[c]	30	1.3×10^{-3}	6.5×10^{-4}	1.7×10^{-1}	4.4×10^{-2}
V. cholera[c]	10^3	6.2×10^{-3}	3.1×10^{-3}	6.0×10^{-1}	1.5×10^{-1}
S. typhi[c]	10^4	6.2×10^{-3}	3.1×10^{-3}	6.0×10^{-1}	1.5×10^{-1}

b. Eating 100 g (3 leaves) of long-leaf lettuce irrigated with treated wastewater effluent meeting the WHO guidelines for unrestricted irrigation of vegetables (1000 FC/100 ml) once or for 150 days/year.

		One-time risk		Annual risk	
Pathogens	$(N_{50})^a$	P_I	P_D	P_I	P_D
Rotavirus[b]	5.6	2.7×10^{-7}	1.3×10^{-7}	4.0×10^{-5}	1.0×10^{-5}
Hepatitis A virus[c]	30	1.3×10^{-7}	6.5×10^{-8}	1.9×10^{-5}	4.7×10^{-6}
V. cholera[c]	10^3	6.2×10^{-7}	3.1×10^{-7}	9.2×10^{-5}	2.3×10^{-5}
S. typhi[c]	10^4	6.2×10^{-7}	3.1×10^{-7}	9.2×10^{-5}	2.3×10^{-5}

[a]Number of pathogens that infect 50% of the exposed population
[b]$\alpha = 0.265$
[c]$\alpha = 0.2$

cucumbers and 3 leaves of lettuce in 1000 would carry a single enteric virus. According to these estimates of pathogen ingestion, it was estimated that the risk of infection and disease that might result from irrigating lettuce with raw untreated wastewater would vary between 1.5×10^{-1} and 5×10^{-2} or 5–15%/year for each of the four diseases studied, with a total of 40% of the population becoming ill with these four diseases each year. To remain on the cautious and conservative side annual total disease risk of some 20% for a range of vegetable crops irrigated with untreated wastewater was assumed. Table 5.1a presents the estimated risk of irrigating lettuce with untreated wastewater, which is a higher than that for cucumbers.

However, if the effluent is treated to meet the WHO guidelines of 1000 FC/100 ml for irrigation of vegetables to be eaten raw, the risk of infection and disease estimates for lettuce are those shown in Table 5.1b. The risk assessment of consuming 100 g cucumbers irrigated with effluent meeting the WHO guidelines for *V. cholera* is 10^{-9} for a one-time risk of infection or disease, whereas in the case of lettuce it is approximately 10^{-7} (Table 5.2). The annual risk of *V. cholera* from eating lettuce is between 10^{-5} and 10^{-6}.

Table 5.2. The risk of infection and disease caused by *Vibrio cholera* from eating 100 g of cucumbers or 100 g of long-leaf lettuce irrigated with untreated or treated wastewater effluent meeting the WHO guidelines for unrestricted irrigation.

Type of wastewater	Type of vegetable	One-time risk of infection[a] P_I	One-time risk of disease[a] P_D
Untreated	Cucumber	6.2×10^{-5}	3.1×10^{-5}
Untreated	Lettuce	6.2×10^{-3}	3.1×10^{-3}
Treated[b]	Cucumber	6.2×10^{-9}	3.1×10^{-9}
Treated[b]	Lettuce	6.2×10^{-7}	3.1×10^{-7}

[a]$N_{50} = 10^3$ and $\alpha = 0.2$
[b]Treated according to the WHO guidelines of 1000 FC/100 ml.

Is this a high- or low-risk level? To shed some light on what are considered reasonable levels of risk for communicable disease transmission from environmental exposure it should be noted that the USEPA has determined that guidelines for drinking water microbial standards should be designed to ensure that human populations are not subjected to a risk of infection by enteric disease greater than 10^{-4} (or 1 case per 10,000 person/year) (Regli *et al.*, 1991). Thus, compared with the USEPA estimates of reasonable acceptable risks for waterborne disease-associated microbes ingested directly in drinking water, the WHO wastewater reuse guidelines appear to be some one or two orders of magnitude more rigorous, if not more.

Validation of the Model

a. The 1970 cholera outbreak in Jerusalem

In 1970 an outbreak of cholera involving some 200 cases of clinical disease occurred in Jerusalem. Our investigation and analysis provided strong evidence that the main route of transmission was through the consumption of vegetables, including lettuce and cucumbers, illegally irrigated with untreated wastewater from Jerusalem, which villagers sold door-to-door throughout the city (Fattal *et al.*, 1986). Since considerable and detailed data pertaining to that epidemic were available, it provided an opportunity to test and validate the risk-assessment model against the actual data. Based on microbial tests carried out during the epidemic and other studies, it was estimated that the concentration of cholera vibrios in the raw municipal wastewater was $10–10^4$/100 ml. It was also assumed, based on the literature (Feachem *et al.*, 1983), that the (N_{50}) for cholera in Jerusalem under conditions of good health and nutrition was 10^5 vibrios. Table 5.2 shows the theoretical risk of infection and disease from cholera, based on the risk-assessment model. The total number of cases of disease reported in Jerusalem was 200 and it was estimated that some 100,000–200,000 persons purchased the contaminated vegetables and were exposed to the pathogen. Thus, it can be estimated that the case rate in Jerusalem was in the order of 10^{-3}–10^{-4}, which falls within the range of the theoretical risk of disease of some 10^{-3}–10^{-5} from lettuce and cucumbers irrigated with untreated wastewater calculated according to the risk-assessment model. It can also be assumed that had the Jerusalem wastewater been treated according to WHO guidelines, the risk of disease transmission by wastewater irrigation would essentially have been negligible, even if the concentration of cholera vibrios in the untreated wastewater had reached the levels it did during the epidemic.

b. The typhoid fever outbreaks in Santiago, Chile, 1978 and 1983

Shuval (1993), who investigated the typhoid fever outbreaks in Santiago in 1978 and 1983, claimed that the use of untreated wastewater for the irrigation of 13,500 ha of various vegetables (tomatoes, lettuce, cabbage, celery, cauliflower), that were consumed raw, was responsible for the transmission of this disease and its high infection rate (~200 cases/100,000 residents). As can be seen in Table 5.1, the one-time risk of becoming ill from *S. typhi* infection due to the consumption of lettuce irrigated with untreated wastewater is 3.1×10^{-3}. The number of cases of both cholera and typhoid fever predicted by this assessment model is validated by the numbers of actual cases in Jerusalem and Santiago. According to this model, if the wastewater in Jerusalem and in Santiago had been treated according to WHO guidelines (1000 FC/100 ml), the risk of cholera or typhoid infection as a result of eating lettuce irrigated with untreated wastewater would have been very small. The risk run by eating tomatoes or cucumbers would have been negligible.

Cost-effectiveness Analysis

The cost-effectiveness associated with meeting the various wastewater effluent guidelines was estimated. As an example, the hypothetical case of a city in a developing country with a population of one million where currently large areas of vegetable crops are irrigated with untreated wastewater is presented. It is assumed that the city is considering the construction of a

wastewater treatment plant to ensure safe utilisation of the effluent for agricultural irrigation of vegetable crops, including those eaten raw. It is assumed that in order to meet WHO guidelines, authorities would opt for a stabilisation pond treatment system with multiple ponds. The authorities would want to compare the cost and risks at that level of treatment with the cost and risks entailed if they did nothing and continued to irrigate vegetables with untreated wastewater, and alternately, if they adopted the USEPA/USAID recommended guidelines for treatment of vegetables eaten raw. For the purpose of this illustration only, the unit cost of wastewater treatment to meet the various guidelines can be roughly estimated as:

	US$
WHO guidelines – 1000 FC/100 ml (in stabilisation ponds)	0.125/m^3
or the annual cost/person (assuming consumption 100 m^3/person)	12.50/person
USEPA/USAID guidelines – 0 FC/100 ml	0.40/m^3
or annual cost/person (100 m^3/person/year)	40.00/person

The estimate of treatment costs to meet WHO guidelines does not necessarily apply to all situations but is generally illustrative of a situation that may apply in hot sunny climates in developing countries where low-cost land is available for effective stabilisation pond treatment. The annual cost of treatment to the recommended WHO guidelines is estimated at some US$12,500,000 for a population of one million persons. According to this estimate, the additional annual cost for that city to meet the USEPA/USAID guidelines would be US$27,500,000.

Assuming that half the hypothetical city's population of one million consumes wastewater-irrigated vegetables on a regular basis, and that the annual risk of contracting rotavirus, hepatitis A virus, *V. cholera* and *S. typhi* infections associated with the use of vegetables, eaten raw and irrigated with untreated wastewater is the worst case, it is assumed that these vegetable crops are currently irrigated with untreated wastewater, and based on conservative risk estimates some 20% of the exposed half of the population, or 100,000 people become ill every year from one of the four diseases.

There would be 10 (10×10^{-5}) cases of rotavirus, 5 (4.7×10^{-6}) cases of hepatatis A, and 23 (23×10^{-5}) cases each of cholera and typhoid, making 61 cases in all (Tables 5.1b and 5.3). If it is assumed that the USEPA/USAID guidelines, that call for no detectable FC/100 ml, entail an essentially zero risk of disease, then it can be estimated that these annual cases of diseases could have been prevented if the USEPA/USAID microbial guidelines had been met. The additional cost of wastewater treatment would be about US$5,500,000 for each case of hepatitis A prevented. In the case of rotavirus disease, the cost would be some US$2,750,000; and US$1,200,000/case for *V. cholera* and *S. typhi* infection prevented. From Table 5.3 it can be seen also that: the greater the α value the higher the cost of prevention, that could reach as high as US$13.75 million to prevent a single case of hepatitis A. If it is assumed that all four infectious diseases are endemic and transmitted simultaneously then to prevent all 61 cases/year resulting from the four listed pathogens, it would cost US$27,500,000, i.e. on average, the cost of preventing a single case would be US$451,000. Nevertheless, if the true level of risk associated with the WHO guidelines is closer to the 10^{-6} level, then no detectable reduction of risk would be gained by the additional annual investment of US$27,500,000 required to meet the USEPA/USAID effluent guidelines. These figures are estimated by the less-conservative interpretation of the results of this study. It is questionable whether this level of additional treatment, requiring major extra expenditure, is justifiable to further reduce the negligible low levels of risk of infection and disease that these estimates indicate are associated with the new WHO guidelines.

Let us look at the cost-effectiveness of treating the wastewater to the WHO recommended guidelines for this city of one million as compared to the situation of continuing the irrigation of vegetables eaten raw with untreated wastewater. If the present state of no treatment and irrigation with untreated wastewater were to continue, the community would be faced with some 100,000 annual cases of the four enteric diseases included in this study. By building a treatment plant that achieves the

Table 5.3. The annual cost in a city with a population of one million of preventing a single case of a particular disease caused by a specific pathogen due to eating lettuce irrigated with effluent according to WHO guidelines (1000 FC/100 ml), at a rate of 100 g/day for a total of 150 days.

Pathogen	α	Cases/year	Cost of preventing all cases/year (US$ millions)	Cost of preventing a single case/year (US$ millions)
Rotavirus	0.265	10	27.5	2.75
Hepatitis A virus	0.2	5	27.5	5.5
	0.5	2	27.5	13.75
V. cholera	0.2	23	27.5	1.2
	0.5	6	27.5	4.6
S. typhi	0.2	23	27.5	1.2
	0.5	6	27.5	4.6

WHO guidelines some 99,940 cases of disease could be prevented each year at an estimated annual total cost of some US$12,500,000 or US$125/case of disease prevented. This can be considered reasonably cost-effective and a worthwhile investment in public health disease prevention. However, each community must make its own judgment as to the level of investment it is prepared to make in preventing disease.

It should be recalled, however, that the health burden incurred by the different diseases varies, and that each disease should be considered separately. Accordingly, WHO and the World Bank have developed another method of evaluating health risk by comparing different diseases on one scale, disability adjusted life years (DALY) (Murray and Lopez, 1996).

Disability Adjusted Life Years (DALYs)

In this study the health effects of the four infectious diseases are considered equally, the WHO and the World Bank have developed a new methodology that measures their relative public health burden by comparing the weight of the damage incurred by the diseases (DALYs) rather than by counting the total number of cases of each disease. DALY emphasises the real health weight of the diseases, that might in some cases be fatal and/or cause long-term damage such as liver injury due to hepatitis A or paralysis in poliomyelitis. This integrated measure combines the number of years of life lost (YLL) by mortality with the number of years lived with a disability (YLD). These are standardised by severity weights. DALY is equal to the sum of YLL + YLD. YLL is calculated by multiplying age-specific mortality rates by the life expectancy of the fatal cases that have not developed the disease. YLD is calculated by multiplying the number of cases by the average duration of the disease and a weight factor that reflects the severity of the disease on a scale of 0–1 (death).

As an example, the DALY of two intestinal diseases: hepatitis A and salmonellosis is calculated:

DALY for 1000 cases of hepatitis A

Assuming that:

Average number of days of disability	40
Severity factor	0.5
Death rate	1%
Life-time disability from liver damage	10%

Therefore:

YLD for 40 days is:

$$1000 \text{ cases} \times 40/365 \times 0.5 = 55$$

YLL:

$$1000 \text{ cases} \times 1\% \text{ death} \times 45 \text{ years} = 450$$

(assuming that the person died at the age of 30 and that the life expectancy is 75 years);

YLD for liver damage is:

$$1000 \text{ cases} \times 10\% \times 45 \text{ years} \times 0.5 = 2{,}250$$

Thus the total DALY for hepatitis A is:

$$55 + 450 + 2{,}250 = 2{,}755.$$

DALY for 1000 cases of salmonellosis

Assuming that:

Average number of days of disability (YLD)	4
Severity factor	0.2
Death rate	0%

Thus the total DALY for 4 days of disability is:

$$1000 \text{ cases} \times 4/365 \times 0.2 = 2.$$

Therefore, the ratio of hepatitis A:salmonellosis is 2,755 : 2 = 1,378 : 1

It can be seen that in this example the disease that has real public health burden is hepatitis A and not salmonellosis (the weight of damage of one case of hepatitis A is equal to 1,378 cases of salmonellosis), since hepatitis A causes death or has a life-long effect. Therefore, an approach that considers the number of cases rather than the weight of diseases according to their real damage (calculated in DALY) is less accurate. It is more justifiable to calculate cost-effectiveness based on preventing diseases like hepatitis A or poliomyelitis that cause heavy health damage, rather than salmonellosis or rotavirus infections. The use of the DALY approach is more logical for this type of risk/cost-effectiveness analysis. For example, it might be more reasonable just to estimate the cost of preventing the one important disease (hepatitis A) rather than pooling all the other less-important infectious diseases (Shuval *et al.*, 1997).

Discussion and Conclusions

A model for the assessment of risk of infection and disease associated with wastewater irrigation of vegetables, eaten raw, has been developed based on a modification of the Haas *et al.* (1993) risk-assessment model for drinking water. The modifications include laboratory experiments to determine the amount of wastewater that could cling to such irrigated vegetables as cucumbers and lettuce, and an estimation of the concentration of pathogens that would be ingested by consuming vegetables irrigated with wastewater of different standards. Validation of the model with data from the Jerusalem cholera epidemic and typhoid fever outbreaks in Santiago which, in both cases, were caused primarily by the consumption of wastewater-irrigated vegetables, lends support to the assumption that the risk-assessment model can provide a reasonable approximation of the levels of disease that really can and have occurred due to irrigation with poor-quality wastewater. Risk assessment, using this model of irrigation with treated wastewater effluent that meets the WHO guidelines for vegetables eaten raw (1000 FC/100 ml), indicates that the annual primary infection risk of a disease such as hepatitis A is about 10^{-5} to 10^{-6}, and of diseases caused by rotavirus, *V. cholera*, and *S. typhi* – about 10^{-5} to10^{-6}.

It is worth mentioning that in developing the risk-assessment model, the worst possible scenario was used in order to reduce the uncertainty factor, and that disease transmission due to secondary infection was not taken into consideration. Therefore, the total number of cases may be higher than the number estimated on the basis of primary infection. The USEPA has determined that guidelines for drinking water microbial standards should be designed to ensure that human populations are not subjected to an annual risk of enteric disease infection greater than 10^{-4} (Regli *et al.*, 1991). Thus, this study suggests that the WHO wastewater effluent reuse guidelines provide a safety factor some one to two orders of magnitude greater than that called for by the USEPA for microbial standards for drinking water. Current findings correlated well with those recommended by Blumenthal *et al.* (2000), based on the revised WHO guidelines for treated wastewater used for agriculture (WHO, 1989).

According to the cost-effective analysis, the data suggest that the additional degree of risk reduction that might be attained by meeting the USEPA/USAID guidelines for water reuse (that require no detectable FC/100 ml), would, according to the most conservative estimate, result in expenditure of some US$1.2–5.5 million per case of disease prevented when $\alpha = 0.2$. However, if $\alpha = 0.5$ the cost would be as high as US$13.75 million. It is questionable whether such additional investments in high technology wastewater treatment facilities designed to meet the USEPA/USAID guidelines rather than the WHO guidelines, are justifiable, considering the small degree of additional health protection they might provide. However, the variable health burden incurred by the different

diseases calculated as DALYs should also be considered.

Major chapters in this volume are devoted to the views of their authors on the benefits of using untreated wastewater in agriculture. In these authors' estimates the risk of becoming ill with an infectious disease, including very serious diseases with significant death rates and long-term consequences such as hepatitis A, from the consumption of salad crops irrigated with untreated wastewater is very high. It is conservatively estimated that some 20% of the exposed population (those eating raw vegetables) will become ill every year with one of the four diseases included in this study if they eat vegetables irrigated with untreated wastewater. The cost-effectiveness of treating wastewater to the WHO recommended guidelines against continuing to irrigate vegetables eaten raw with untreated wastewater would be about US$125/case of disease prevented. This can be considered a reasonably cost-effective level and a worthwhile investment in public health disease prevention. However, each community must make its own judgment on the level of investment it is prepared to make in preventing disease.

It must be pointed out that the model used in this study estimates the risk of infection and disease only of those who consume raw vegetables irrigated with untreated wastewater. It does not include the health risks to the farmers and irrigation workers exposed to untreated wastewater. Earlier studies (Shuval *et al.*, 1986) have shown that these risks are considerable, particularly in areas where hookworm and other parasitic diseases are endemic. Thus, in the authors' view, irrigating vegetable crops eaten raw with untreated wastewater is not a desirable public health practice. Treating wastewater to significantly reduce the concentration of pathogens along the lines recommended by the WHO appears to be the right way to go. But even somewhat less-rigorous treatment levels that are less costly could provide significant cost-effective health benefits. This study did not evaluate such alternative degrees of treatment.

It should also be noted that one of the common risks associated with present lifestyles is road accidents, which in Israel alone, reach an annual total of 7×10^3 injured. This value is similar to the risk of infection from eating untreated wastewater-irrigated vegetables, which can be lowered by 2–3 orders of magnitude if wastewater is treated to meet the WHO guidelines. Then too, injuries incurred by road accidents are far more serious and lethal than the enteric diseases resulting from the ingestion of vegetables irrigated with wastewater effluent. This example is presented in order to raise the issue that health-protecting investment should bear some rational relationship to the risks involved and the cost-effectiveness of the preventive measures.

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6 Wastewater Irrigation – Hazard or Lifeline? Empirical Results from Nairobi, Kenya and Kumasi, Ghana

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Abstract

The range of factors that determine the quality of wastewater used by different irrigators is described, drawing on case studies from Nairobi, Kenya and Kumasi, Ghana. Not all urban irrigation relies on raw wastewater and it is misleading to consider wastewater as a uniform commodity. Dilution and natural remediation mean that irrigators use a range of water qualities and the authors raise the question of when a dilute wastewater stream is no longer classed as wastewater. World Health Organization (WHO) guidelines for the design of wastewater treatment plants are widely used as standards to judge the quality of untreated irrigation water. However, because of the gap between standards that lead to 'no measurable excess risk of infection' and the actual situation pertaining in many cities, urban planners either condemn all urban irrigators as posing a major health risk to the community, or turn a blind eye. The authors argue that a standard leading to 'no measurable excess risk' to health is an unattainable and unhelpful medium-term goal under the conditions of indirect wastewater use seen in many cities. Instead, there is a need for explicit debate of the levels of risk that may be acceptable to individuals and communities, and the costs and benefits that they bring with them. Informed debate, that is enabled to assess the risks associated with different water qualities and irrigation practice, may lead to the development of local water quality norms and wastewater management that account for the physical and social environments in which wastewater irrigation is actually practised.

Introduction

Types of urban wastewater irrigation

The information presented here comes from a larger study of urban and peri-urban irrigation practices carried out in Nairobi, Kenya and Kumasi, Ghana, from 1998 to 2001. That research aimed to describe and quantify the nature, extent and importance of informal, irrigated agriculture in the urban and peri-urban zones of those cities (Cornish *et al.*, 1999, 2001; Cornish and Aidoo, 2000; Hide and Kimani, 2000; Hide *et al.*, 2001). The research focus was not confined to irrigation with wastewater or the hazards associated with its use. Rather, the intention was to understand the range of practices that exist with regard to water sources, water and crop management, crop marketing, and the contribution of informal urban and peri-urban irrigation to household income and expenditure. The research showed that in both cities a minority of irrigators use the urban potable water

 Wastewater Use in Irrigated Agriculture (eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

supply; many use shallow groundwater that is polluted to varying degrees whilst others draw water from streams or rivers that are also polluted to varying degrees by untreated, industrial and municipal wastewater. In Nairobi, 34% of the irrigators sampled diverted untreated sewage from trunk sewers directly onto their land. In Kumasi there is no extensive piped sewerage network and urban wastewater is either collected in septic tanks that are periodically emptied by tanker, or it is discharged directly into the small streams and rivers that drain the urban area. Tankers that empty the septic tanks discharge their contents into derelict waste stabilisation ponds that overflow directly into a river. Thus, whilst there is no direct use of untreated wastewater in Kumasi, many irrigators who draw water from the rivers downstream of the city are using a diluted wastewater stream. Table 6.1 summarises the different water sources used by informal irrigators in the two cities.

Table 6.1. Percentage of urban and peri-urban irrigators sampled drawing water from different sources.

Source	Nairobi (%)	Kumasi (%)
River/stream	51	38
Shallow well	4	46
Sewerage main	34	0
Urban potable water supply	3	3
Other (pool, deep well, etc.)	8	13

In introducing this chapter the following points are emphasised:

1. *Treated* wastewater is not being used for irrigation in either city to the best of the authors' knowledge. Irrigation is informal and irrigators obtain water where they can. In many cases their water source is highly polluted and in Nairobi raw sewage is used. It seems reasonable to presume that informal use of dilute and undiluted, *untreated* wastewater is common in other urban areas in sub-Saharan Africa.
2. It is an over simplification to consider 'urban wastewater irrigation' as a single activity with uniform characteristics, amenable to a standard response from planners, policy makers or technologists. Rather, there is a range of different physical conditions under which urban wastewater irrigation occurs. These conditions influence both the levels of risk to health faced by growers and consumers, and possible interventions that may reduce those risks while maintaining the benefits to irrigators and possibly to the wider environment. Recognition of this variation in conditions is essential to any effective discussion of wastewater irrigation practice, or to the formulation of recommendations regarding its regulation.
3. The issue of mixing, and thus diluting wastewater, with water from a natural water body merits comment: at what point does urban wastewater become simply a polluted water body? Many will know of urban 'rivers' and other water bodies that are little more than open sewers or cesspits. Although some mixing and dilution of wastewater has occurred in these water bodies it seems misguided to exclude them from a consideration of wastewater irrigation as they are characterised by the presence of urban wastewater. There is a need to define a level of dilution at which wastewater becomes polluted 'natural' water, but proposing that definition lies beyond the scope of this chapter.

Figure 6.1 shows the range of factors that determine the nature of wastewater irrigation at any location. The only non-physical factor considered is whether the irrigation takes place in a formal (authorised) or informal (unauthorised) setting. The figure does not include the wider social, economic or institutional factors that influence any given practice, although these are recognised as having an important influence on irrigators' behaviour.

Figure 6.1 may not constitute a formal typology of wastewater irrigation, but it emphasises the range of factors that influence both the physical and biochemical quality of wastewater used for irrigation. The elements of Fig. 6.1 are used to describe three different types of wastewater irrigation practice drawn from sites in Nairobi and Kumasi.

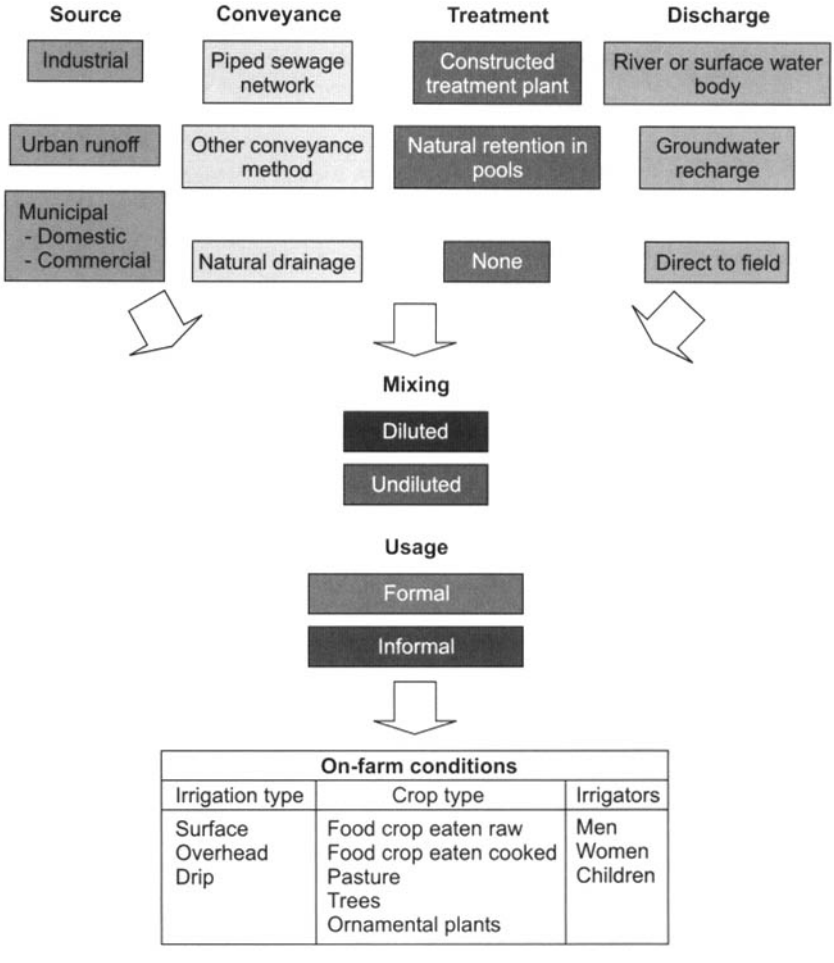

Fig. 6.1. Factors determining the nature of wastewater irrigation. Diluted = Effluent mixed with other water before use in irrigation. Undiluted = No significant dilution of the effluent in a river or other water body before use in irrigation. Formal use = Use of wastewater with a certain level of permission and potential control by state agencies. Informal use = Use of wastewater without permission and control by state agencies.

Physical factors include the source of the wastewater, the means by which it moves from the source to the field, and whether or not any treatment occurs. 'Discharge' describes whether or not the wastewater is discharged into an intermediate water body – surface or groundwater – where dilution occurs before an irrigator obtains it for use. The differentiation between formal and informal (authorised/unauthorised) irrigation – an institutional factor – is often determined by whether the wastewater is obtained from a small number of potentially controllable locations, or from numerous, unknown locations. The on-farm conditions identified are those considered to have the greatest influence on the level of risk to health for either the irrigators or those consuming the crops they produce.

Types of Wastewater Irrigation in Nairobi and Kumasi

Mau Mau Bridge, Nairobi

Mau Mau Bridge lies upstream of Nairobi's city centre and its industrial zone (see Fig. 6.2). There are irrigated farm plots adjacent to the Nairobi River. Farmers have constructed small dams and weirs in the river to divert water through channels to the lower areas of their farm plots. Using buckets and watering cans, water is drawn from hand-dug ponds at the end of the channels, to irrigate crops at higher elevations in the farm plots. On-farm irrigation methods therefore include surface furrows or basins and overhead sprinkling from cans.

Although Mau Mau Bridge is situated upstream of the main city and industries, slums are located on the slopes above the Nairobi River. Waste and wastewater from the slums are dumped onto the streets and into natural drainage channels from where they find their way into the river. Thus, untreated municipal wastewater mixes with river water and it is this mixed water that the irrigators at Mau Mau Bridge use.

A typical plot size is 60 × 20 m and farmers grow a mixture of vegetables, including tomatoes, cabbage, spinach, maize and French beans. Some of these are eaten raw and others are cooked before consumption. Crops are mainly grown for the local market but small quantities are also consumed by the irrigators' families. All members of the irrigators' families carry out irrigation and other farm work.

Maili Saba, Nairobi

Maili Saba is 15 km east and downstream of Nairobi city (see Fig. 6.2). There are both similarities and contrasts with Mau Mau Bridge in the way wastewater is obtained and

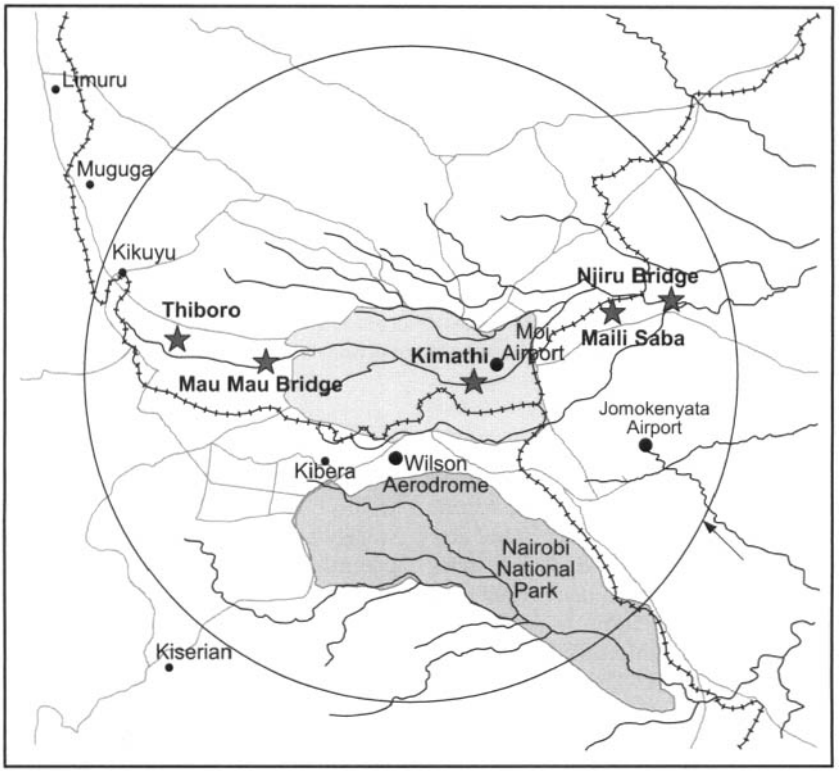

Fig. 6.2. Location of water-sampling sites (★) with a 20 km radius of Nairobi city centre (Hide *et al.*, 2001).

used. At both sites the practice is informal with no government permission or infrastructure provided to support irrigation. However, at Maili Saba farmers remove manhole covers and block the city's main sewer, diverting raw sewage onto their land. Their plots, typically 20 × 40 m, are irrigated by surface irrigation from a hand-dug canal system. Buckets or watering cans are not used. Irrigators grow kale, sweet potato, arrowroot and some green maize – crops that are cooked before being eaten. Much of the production is for home consumption but some is sold at the local markets. Assuming that the produce is well cooked the health risks associated with the use of undiluted sewage are confined to the family members including men, women and children who carry out the irrigation.

Asago, Kumasi

Asago is situated 9 km downstream of Kumasi at the confluence of the Sisa and Oda Rivers (see Fig. 6.3). The Sisa collects untreated and partially treated municipal wastewater and untreated industrial wastewater. The wastewater constitutes municipal and industrial effluent, conveyed to the river by both road tankers and natural drainage flows. Farmers at Asago draw irrigation water from the perennial River Oda either by bucket, or other container or using motorised pumps (hired or owned). Considering the factors identified in Fig. 6.1, wastewater irrigation at this site is informal use of diluted wastewater using river water that has been mixed with untreated or insufficiently treated wastewater from stabilisation ponds.

All farmers use some form of overhead application to irrigate a mix of vegetable crops including tomato, African aubergine (*Solanum integrifolium*) okra and chilli, some of which are always cooked and others eaten raw. Water is applied with watering cans, buckets or perforated tins. Irrigators who use pumps use PVC pipes to convey the water from the pump to a position within their fields and connect a short length of 50-mm lay-flat hose to the final pipe length. A worker then stands and sprays water from the hose-end onto the crop.

The vegetables are mainly grown for the Kumasi market but small quantities are also consumed at home by all members of the family, who carry out irrigation and other farm work.

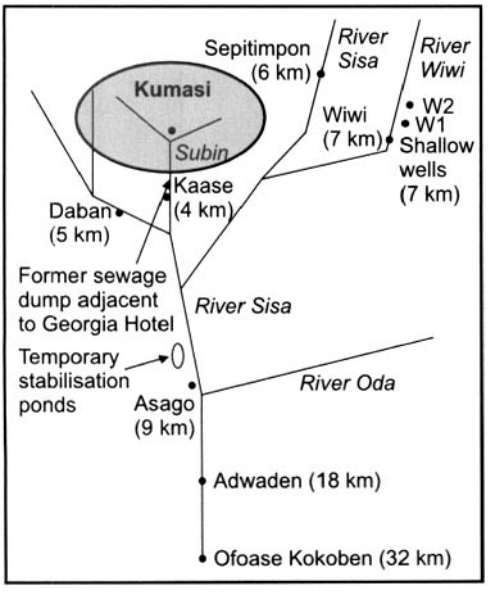

Fig. 6.3. Location of water-sampling sites relative to Kumasi city centre (Cornish *et al.*, 1999).

Variations in Water Quality Between Sites

Field measurements of faecal coliform numbers demonstrate the large variation in microbiological water quality between sampling sites and the danger of considering all urban wastewater irrigation as equal. In all but two of the sites the mean faecal coliform count exceeds the World Health Organization (WHO) *Health Guidelines for Use of Wastewater in Agriculture and Acquaculture* (WHO, 1989) but the degree of exceedence varies widely. The question of whether guidelines, developed for the design of wastewater treatment plants assuming a requirement for 'no measurable excess risk' are appropriate and adequate for making judgements of health risk in diverse field conditions such as these, lies at the heart of this chapter and is examined in more detail below.

Following the example of Westcot (1997) mean faecal coliform count was used as the sole

indicator of biological water quality for health risks. It is recognised that helminth infections pose the greatest of the risks associated with wastewater irrigation and that the WHO guidelines specify threshold values for both faecal coliform and helminth egg numbers. However, whilst laboratories and technicians are readily able to measure faecal coliform numbers, procedures for the accurate detection of helminth eggs are more demanding and less widely known. For this pragmatic reason, helminth egg numbers were not measured or reported.

Figure 6.4 shows the mean numbers of faecal coliforms recorded at different locations in a. Nairobi and b. Kumasi. Five samples were collected at 10-day intervals over a 40-day period. The sampling sites included three river sites, one well and one sewerage outlet. Their location relative to Nairobi City centre is shown in Fig. 6.2. The sampling sites in Kumasi included seven river sites and two wells. Their locations relative to central Kumasi are shown schematically in Fig. 6.3. Five samples were collected at 6-day intervals over a period of 26 days. In both cities the sampling period coincided with the dry season, when irrigation is mainly practised.

Most of the data from Nairobi show very high levels of pollution. Numbers of faecal coliform in the Nairobi River at Kimathi and Njiru Bridge, both situated downstream of the city centre, are as high as those recorded in effluent drawn directly from sewerage mains at Mailli Saba. This is 10,000 times greater than the limit for unrestricted irrigation recommended by the WHO design guidelines for treated wastewater. Water at Mau Mau Bridge contains faecal coliform numbers that are 10 times greater than the recommended value. Mau Mau Bridge is situated upstream of Nairobi's city centre where the Nairobi River water has only been mixed with municipal wastewater collected and disposed into the river through natural drainage channels. Only water drawn from the shallow well at Thiboro, upstream of Nairobi, yields water that lies within the WHO guideline limits.

In Kumasi levels of pollution are generally lower, with water from the two sites upstream of the city centre lying on or near the WHO threshold value for unrestricted irrigation. Asago, the most highly polluted site, exceeds the guideline by only 2-log. At Asago farmers draw their water from the perennial River Oda. This water is mixed with municipal and industrial effluent conveyed to the river by road tankers and natural drainage flows.

There is clearly great variation in the quality of the water used at different locations. This must be recognised in evaluating the likely health risks. Single threshold values, intended as a guideline in the design of treatment plants, even when they account for different forms of irrigation and crop types say nothing about the different levels of risk posed at these various sites.

Positive Impacts of Urban Wastewater Irrigation

The extent of urban wastewater irrigation and its contribution to food security

The areal extent and the number of households relying on irrigation within the two study areas are shown in Table 6.2. It is important to note that not all of these irrigators are directly reliant on wastewater. The two city studies characterised urban and peri-urban irrigation irrespective of water type. Farmers using shallow groundwater in areas remote from rivers draining the urban centres are not using a wastewater source, although the shallow wells

Table 6.2. Extent of informal irrigation in the study areas.

City	Gross study area (km^2)	Mean irrigated plot area[a] (ha)	Minimum number of households involved in irrigation	Estimated minimum area of irrigation (ha)
Kumasi	5,027	0.94	12,700	11,900
Nairobi	1,257	0.60	3,700	2,220

[a] Estimates are based on sampling of 410 farmers in Kumasi and 158 farmers in Nairobi.

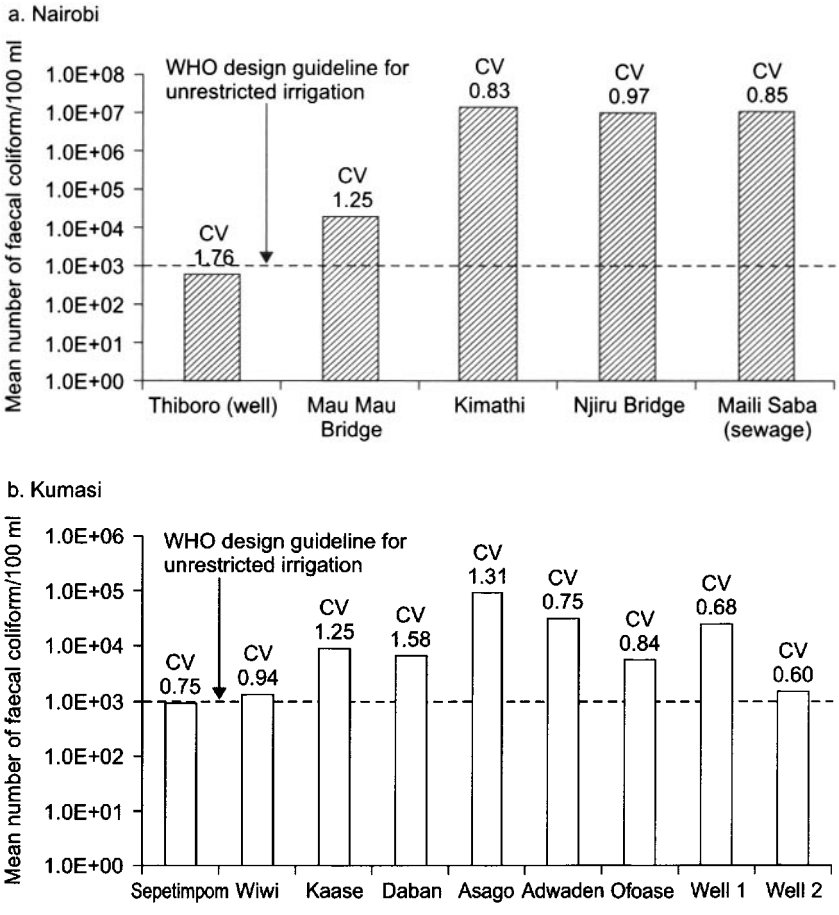

Fig. 6.4. Geometric mean faecal coliform (count/100 ml) and coefficient of variation (CV) at different sites in Nairobi (mean of at least 5 sampling dates (Hide *et al.*, 2001).

sampled in Fig. 6.4 still indicate relatively high levels of faecal coliform contamination in the water they use.

The large area of informal irrigation within a 40-km radius of Kumasi contrasts with the 6,400 ha under formal irrigation reported in the Food and Agriculture Organization's (FAO's) statistics for the whole of Ghana (FAO, 1995). Kumasi alone supports an area of informal irrigation almost twice that of all formal irrigation in the country, and further substantial areas of informal irrigation exist around Accra and Takoradi.

The smaller area of informal irrigation identified around Nairobi was recorded over a much smaller study area. Irrigated crop production is, for many, a relatively new activity. It is quite possible that such wastewater irrigation will continue to expand in the coming years. Figures on irrigated areas in Kenya for 1998 reported by the Ministry of Agriculture and Rural Development (cited by Muchangi in HR Wallingford, 2001) identify only 1,500 ha of urban irrigation for the whole country. This study identified more than 2,200 ha of informal irrigated agriculture within 20 km of the centre of Nairobi. As in Ghana, it appears that the extent and importance of urban irrigation is under-reported in official statistics.

In Nairobi, the average annual revenue per ha from irrigated plots is US$1,770, indicating that from the urban irrigated sector vegetables worth as much as US$3.9 million are being used in Nairobi each year. The seasonal (Nov-

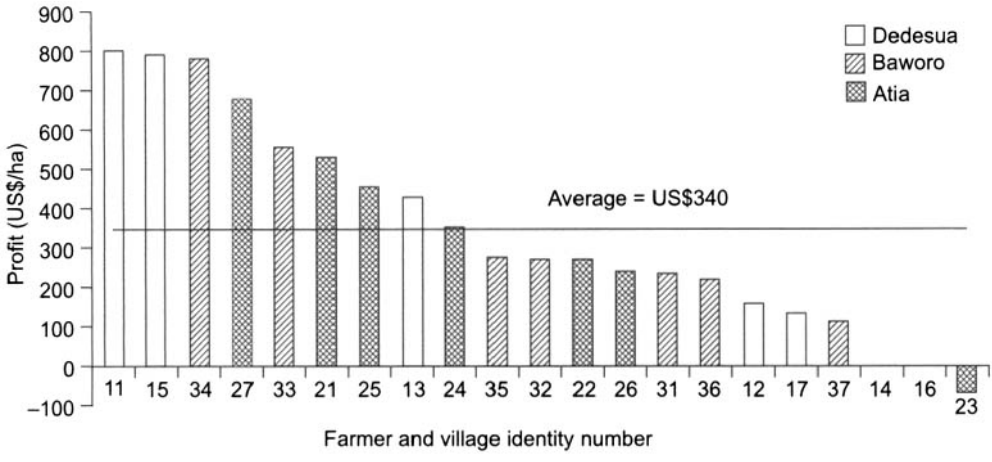

Fig. 6.5. Seasonal (November-May) profits (US$/ha) from irrigated cropping for 21 Kumasi farmers in three villages (Cornish *et al.*, 2001).

ember–May) average revenue per ha for production around Kumasi was US$544 indicating a total value of food production in excess of US$6 million.

The studies did not determine what fraction of the total annual vegetable consumption of the two cities these production figures represent, and did not consider that all of the production does not pass through the main city markets; some is sold in smaller, local markets outside the urban centres. However, it is clear that informal urban irrigation, much of which relies on wastewater sources, contributes significantly to the supply of fresh vegetable produce in both Nairobi and Kumasi.

Contribution of urban wastewater irrigation to the livelihoods of irrigators

Income generation is the main objective for most irrigators in Nairobi and Kumasi. Only a small percentage of the farmers surveyed said that directly supplementing their food supply was their main goal. By generating cash income, urban irrigation is an important means of alleviating poverty and enhancing livelihoods.

The average profit recorded in three different peri-urban villages around Kumasi is remarkably similar, indicating that different sources of water, distance to market, or other factors determined by location do not have a major influence on profit. There is certainly no evidence that water quality influences levels of income in the Kumasi study.

Although average profit in each village is similar, Fig. 6.5 shows that there is a wide range of levels of profit recorded by individual farmers. Numbers on the x-axis identify individual farmers – farmers 11–17 from village 1 (Dedesua), 21–27 from village 2 (Baworo) and 31–37 from village 3 (Atia). Farmers from all three villages are distributed across the whole range of profit per ha. Although the average profit is around US$340/ha, four of the farmers recorded profits of between US$650–800/ha. As the actual plot sizes are much smaller than a hectare the actual profits of these four farmers were in the range of US$220–470.

The situation in Nairobi is quite different. On average, incomes and profits per hectare are higher than in Kumasi, but plot sizes are much smaller. Furthermore, there is a clear trend in the levels of expenditure, income, and profit according to location.

Farmers to the east of Nairobi, at Thiboro operate on a commercial basis, albeit on very small plots, investing heavily in paid labour and other production inputs. Levels of revenue and profit reflect this investment with an average actual profit (from 0.126 ha) of US$607 (US$4,816/ha). At Mau Mau Bridge there is high

investment in production inputs, but no use of hired labour. The average revenue during the period of study was low due to a pest attack on a crop of green peppers. This clearly illustrates the relatively high-risk nature of irrigated vegetable production. Average actual profit was just US$86 or US$1,036/ha. The agricultural practices at Maili Saba are more subsistence in nature. Few exotic market vegetables are grown and very few inputs are purchased. Actual average profits were about US$70 (US$1,404/ha) during the study period June–September 2000.

Trade-offs of urban wastewater irrigation

The case studies show that urban wastewater irrigation has a positive effect on the financial capital of the urban irrigators. However, wastewater irrigation potentially bears risks that may weaken the human, natural, and social assets of the irrigators and their families, making them more vulnerable to external shocks. Apart from the direct risk to health, water polluted with industrial effluents may also pollute soil and groundwater, thereby undermining the long-term sustainability of the natural resource base. An analysis of the risks would help to understand the actual trade-offs on the sustainability of the livelihoods of urban irrigators and their families: Do the benefits outweigh the risks and negative impacts of wastewater irrigation, and over what time frame should such benefits and costs be assessed? The recent increases in the numbers of urban dwellers engaging in urban wastewater irrigation in Nairobi and Kumasi indicate that in irrigators' and family members' own assessment the benefits outweigh the risks, at least in the short term.

Whatever the benefits may be for the irrigators, policy makers must safeguard the wider public interest. Although irrigation with untreated wastewater contributes substantially to the availability of fresh vegetables, and under controlled circumstances may be environmentally acceptable and a beneficial means of waste disposal, uncontrolled wastewater irrigation can lead to both chronic ill-health and more serious outbreaks of disease amongst irrigators and consumers. Policy makers and others working in this field need clearer guidance on the levels of risk associated with use of different qualities of untreated wastewater if they are to assess the trade-offs that exist between the costs and benefits. Some types of wastewater irrigation documented in these studies are probably unsustainable and may be regarded as unacceptable by most communities, when given information. However, in the absence of guidelines aimed specifically at the management of untreated wastewater irrigation it is difficult to make informed judgements about the costs, benefits, and trade-offs, associated with different practices.

The Dilemma

At present there are no microbiological irrigation water quality standards that acknowledge the concept of an acceptable level of health risk for irrigators and the wider community, other than zero risk. In the absence of other norms, the WHO microbiological quality guidelines for the design of wastewater treatment plants, where the effluent is intended to be used for irrigation, are used extensively to evaluate the health risks arising from the use of polluted water sources for irrigation (WHO, 1989). These guidelines are designed to ensure **'no measurable excess risk'** of infection attributable to the use of wastewater as evaluated from epidemiological studies and risk assessment models. The guidelines prescribe that for unrestricted irrigation the faecal coliform (FC) count may not exceed 1,000/100 ml and that the helminth egg count should be below 1/l. FAO promotes the use of these guidelines to monitor the quality of water used to irrigate vegetables and other high-risk crops in the absence of other microbiological irrigation water quality standards (Westcot, 1997).

In adopting these guidelines for controlling the quality of water used for irrigation two anomalies emerge. Firstly, water for irrigation must meet a higher standard than that set by the British Government's Statutory Instrument 1991 No. 1597 for coastal and freshwater bodies used for bathing (HMSO, 1991), which sets a limit of 2,000 FC/100 ml. Secondly, and more significantly, a high percentage of the world's freshwater resources do not meet WHO water

quality guidelines for unrestricted use, while in practice these waters are diverted for unrestricted irrigation. Data published by WHO (1989) show that 45% of 110 rivers tested around the world have FC levels of above 1,000/100 ml, while 15% have levels over 10,000/100 ml. In China 27% of the river sections monitored have a coliform count of more than 10,000/100 ml. It may be expected that near urban centres the water quality will be poor. Rapid urbanisation is putting further pressure on sanitation and treatment infrastructure that is already inadequate. In developing countries, where the majority of the large cities are located, the costs of necessary investments in water supply, sanitation and treatment facilities are far beyond those countries' present economic potential (Niemczynowicz, 1996). In the foreseeable future, surface water quality close to urban centres is likely to deteriorate further rather than to improve, and irrigators will continue to use it. To insist that only *treated* wastewater be used for irrigation seems an unrealistic goal. What planners and technocrats urgently need is guidance on the levels of risk associated with the use of water whose quality falls below the ideal, 'no risk' threshold set in the present WHO guidelines.

Conclusions

A large number of urban and peri-urban irrigation farmers around Nairobi and Kumasi are using various forms of untreated wastewater for irrigated cropping under unregulated and informal arrangements. In general, both the numbers of irrigators and the volumes of untreated wastewater seem certain to increase in the short to medium term, as urban populations grow and investment in wastewater treatment infrastructure is constrained.

In these two case-study cities the wastewater used for irrigation displays a wide range of microbiological quality depending on location, dilution, and the effects of natural remediation. It is misleading to consider 'wastewater irrigation' as a single activity with uniform characteristics. The various pathways of wastewater acquisition, from source to field, must be identified and differentiation made between them.

Some forms of wastewater irrigation not only offer important financial gain to the growers, they may also represent a low-cost and beneficial means of using and 'treating' wastewater within acceptable and controllable levels of disease risk. However, so long as the focus remains on the management of formally treated wastewater and a policy of 'no measurable excess risk to health', guidance on what might constitute an acceptable risk, the risks associated with different types of practice, and the tools needed to make informed, pragmatic judgements remain lacking.

By using the WHO guidelines to make judgements over the safety of the use of wastewater, without taking the various 'types' of urban wastewater irrigation into consideration, policy makers and technocrats are driven towards inappropriate conclusions. There is inevitably a huge gap between a standard leading to 'no measurable excess risk of infection attributed to the reuse of wastewater' and the situation on the ground. Faced with such a gap, reactions are either to condemn urban irrigators as posing a major health risk to the community or to turn a blind eye because action seems impossible and ignorance is the preferred course. Neither approach is helpful and both are driven by the lack of appropriate standards, inappropriate use of the WHO microbiological quality guidelines for treated wastewater use in irrigation, and a failure to differentiate between different qualities of wastewater flows. In Nairobi, for example, after the publication of studies on informal irrigation in the peri-urban zone, and the wider emergence of 'urban agriculture' as a planning issue, city authorities are now motivated to ban the practice without taking account of the various types of urban wastewater irrigation, and the range of water qualities which largely define the actual risks involved.

As explained by Hespanhol and Prost (1994) guidelines produced by the WHO are intended to provide guidance for making risk-management decisions related to the protection of public health based on current scientific research and epidemiological findings. They provide a common background from which national and regional standards can be derived. However, for the development of national or regional standards the economic, technical, social, cultural and political contexts need to be taken into consideration. Such an

approach inherently incorporates a risk-benefit analysis. Shuval *et al.* (1997) describe a risk-assessment model that estimates the risk of infection associated with eating vegetables irrigated with wastewater of varying microbiological quality. The first step in applying risk-assessment approaches is the definition of an 'acceptable' risk of infection. Therefore, there is a need for explicit debate on the levels of risk that may be acceptable to producers and consumers of wastewater-irrigated crops and the costs and benefits that they bring with them. Pragmatic water quality standards based on such an approach that are pertinent only to the use of untreated wastewater, can better inform policy makers and technocrats as they seek to manage the real situation on the ground.

Acknowledgements

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7 National Assessments on Wastewater Use in Agriculture and an Emerging Typology: The Vietnam Case Study

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Abstract

The use of urban wastewater in agriculture is a common practice for diverse reasons, not least of which are water scarcity, fertiliser value, and lack of an alternative source of water. It is necessary to have a clear understanding of wastewater's importance and significance in terms of extent, agricultural production, and livelihood impacts before appropriate policies, strategies and guidelines for its use in an integrated water management framework are developed. The Vietnam nationwide assessment was the pioneer in a series of such assessments being undertaken by the International Water Management Institute (IWMI). Findings indicate that 75% of domestic wastewater in large cities and 45% in smaller cities are discharged into sewers. Wastewater is used for agriculture or aquaculture in 93% of the cities. On an average wastewater is used in at least 2% of the agricultural land around most cities, predominantly to grow rice. The nationwide total of such irrigation is conservatively estimated at around 9,000 ha. Wastewater aquaculture is carried out in natural ponds which serve the dual purpose of inundation control and as collection sinks for city wastewater. Wastewater agriculture provides a primary or secondary source of income to 1% of the urban population. The corresponding figure for wastewater aquaculture is 0.1%. Factors that influence the use of wastewater in non water-short regions have emerged, showing a possible pattern of wastewater use under these conditions. A key result from this study is the need for a typology that effectively captures all these characteristics, as a prerequisite for a global assessment.

Introduction

The use of urban wastewater in agriculture is a common practice, not only in arid and seasonally arid zones but also in non water-short countries like Vietnam. The reasons for this are diverse and dependent on the situation and local context. For instance, in Pakistan, wastewater is used for its water value even in untreated form, and as a source of plant nutrients. In Ghana it is used because an alternative non-polluted source of water is not available. The added benefit of its fertiliser value is incidental. In Mexico, large areas of land are irrigated with partially treated and/or diluted wastewater.

 Wastewater Use in Irrigated Agriculture (eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

The reasons for wastewater use, the diverse conditions under which it is used, and its impacts are still not clearly understood and require further research before amelioration techniques and technologies can be suggested.

In most developing countries wastewater is used untreated, partially treated or diluted, but policies governing its use are not adapted to the local contexts. A clear understanding of its importance and significance at a global level in terms of extent, agricultural production, and livelihood impacts would contribute to developing appropriate policy and legal frameworks for wastewater use within an integrated water resources management framework.

The Vietnam nationwide assessment is part of an initiative (part of the Comprehensive Assessment of Water Management in Agriculture) to assess the global extent of wastewater use. There are claims that worldwide more than 20 million ha are irrigated with urban wastewater but at present there is a gap in knowledge about global estimates, and the possible trade-offs between health and environmental impacts, and the livelihoods-related benefits for those using wastewater. A survey of literature on wastewater agriculture indicates that this was the first study of its kind ever attempted at a national level, necessitating the design of a research methodology suitable for this purpose. Documenting the situation in Vietnam provided insights on agricultural wastewater use practices where water scarcity is not always the major consideration. It also served to gain an understanding of the constraints and limitations of such an assessment, and the importance of developing a clear typology for future assessments.

Background

Vietnam is one of the developing countries where wastewater has been used for decades – even centuries – by poor farmers in urban and peri-urban areas for both agriculture and aquaculture. Located in the tropical monsoon belt of Southeast Asia, Vietnam has mean annual rainfall ranging from 1700 mm in the north to 2000 mm in the south with temperatures ranging from 13° to 35°C that are favourable for agricultural production, especially paddy rice cultivation. Its territory of 333,000 km^2, with a population of approximately 77.7 million people in 2000, is officially classified into eight geographical regions, namely: northeast (NE) and northwest (NW) mountainous regions, the Red River delta (RRD), north central coast (NCC), south central coast (SCC), central highland (CH), southeast (SE) and Mekong River delta (MRD).

In spite of *doi moi* (renovation) reforms in 1986, the country is still rated one of the world's poorest with a predominance of poverty in rural areas. Irrigation plays a significant role in agricultural production, which represents approximately 25% of the country's gross national product. Despite the general abundance of freshwater resources, wastewater, both domestic and industrial, is used extensively in some areas, e.g. in the peri-urban areas of Hanoi particularly in the Thanh Tri, and Tu Liem districts, where it contributes significantly to food production and food security in the cities. About 80% of Hanoi's vegetable demand is satisfied from wastewater agriculture (Tran Van Lai, 2000), and the system seems to be generally accepted by consumers.

Survey Design

Scope and sample selection

There are 57 provincial capitals in Vietnam distributed within eight geographical regions, and four cities directly under central government rule. In selecting a sample of cities/towns to be surveyed, the following were left out: those in the mountainous NW region (inaccessible), those that had no known wastewater irrigation (e.g. in predominantly forested provinces), and those in the delta floodplains (difficulty in designating specific wastewater irrigated areas). The sample of 30 cities finally selected represented different city classes that are designated in Vietnam according to population and available infrastructure facilities.

The sample cities covered seven of the eight geographical zones (NW excluded). In MRD only one city, Tanan (in Longan province), located southeast of Ho Chi Minh City, was included. The total population of the cities surveyed was 14.7 million amounting to

Table 7.1. Provincial capital cities selected for Vietnam nationwide survey, roman numerals indicate city class.

North		Central			South	
NE	RRD	NCC	SCC	CH	SE	MRD
Viet Tri V	Nam Dinh II	Thanh Hoa IV	Da Nang II	Buon Ma Thuot IV	Thu Dau Mot IV	Tan An IV
Thai Nguyen I	Ninh Binh V	Vinh II	Quang Ngai IV	Da Lat III	Bien Hoa II	
Bac Giang IV	Hai Duong IV	Ha Tinh V	Tuy Hoa IV	Plei Ku III	Ho Chi Minh I	
Bac Ninh IV	Hanoi I	Dong Hoi V	Tam Ky IV		Vung Tau II	
	Hai Phong II	Dong Ha IV	Quy Nhon II			
	Thai Binh IV	Hue II				
	Ha Dong IV					

approximately 19% of the total population of the country (Table 7.1).

Data Collection and Validation

Data on water supply, sanitation and sewerage infrastructure, wastewater generation (sources, management), wastewater agriculture and aquaculture (areas, production, characteristics), and general social, health, and crop impact were collected from secondary data sources and through a questionnaire survey accompanied by indepth interviews administered to officials of the Department of Land Administration, Statistics, Agriculture and Rural Development, Transportation and Public Works, Science, Technology and Environment, and the Irrigation and Drainage Management Company.

Working on the assumption that most wastewater use would be in urban and peri-urban areas of cities, simplified definitions for the following terms suited to the study were developed.

- **Target study area** – the metropolitan area of each city, including its urban centre and the suburban areas falling within the city boundaries.
- **Urban wastewater** – a combination of domestic effluent (both blackwater and greywater), industrial, commercial and institutional effluent including hospital waste, and other urban and storm runoff. Irrigation and drainage canals and other water bodies, which receive untreated wastewater and are highly polluted, may also be considered as wastewater.
- **Wastewater irrigated area**
  a. When water for irrigation was taken from a *wastewater drainage canal* the whole area irrigated with this water was included in the wastewater irrigated areas, e.g. Hanoi agricultural areas.
  b. When water was taken from an *irrigation and drainage dual canal* that was receiving wastewater, the area designated as wastewater-irrigated was limited to the area close to the receiving point where sensory negative impacts on users, e.g. bad smell, itching were known.
  c. When water was taken from an *irrigation canal receiving city wastewater*, the wastewater irrigated area was calculated as a fraction of the irrigated area within the city limits corresponding to the proportion of wastewater in the canal.
- **Wastewater aquaculture** – the use of natural stabilisation ponds and man-made ponds receiving wastewater to cultivate fish.

A pilot study was conducted in Hai Duong city, to test the questionnaire and its relevance, before launching the full-scale exercise. Maps were used when possible to localise areas, and field observations were made when time permitted. Written materials made available by local authorities were also used. Data validation for five selected cities was conducted either through a further visit or by telephone interviews with authorities. No major discrepancies were noted although it must be understood that some of the data were figures provided by the local authorities, with no independent confirmation. Due to lack of secondary data, e.g. domestic and industrial water demand, etc.

in many instances these had to be estimated by local officials. Data reliability turned out to be a major shortcoming that is likely to plague other attempts at national and global assessments despite clear definitions.

Results and Discussion

Classes of cities and population

The survey covered 50% of the largest cities in Vietnam. These cities account for 19% of the national population. The two largest cities, Hanoi and Ho Chi Minh City, accounted for 54% of the population covered.

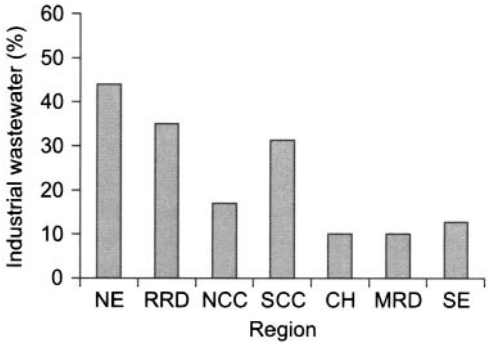

Fig. 7.2. Proportion (%) of industrial wastewater (including hospital wastewater) in total wastewater in various regions (see Fig. 7.1) of Vietnam.

Water supply and sanitation

Surface water provided the sole source of water supply in 12 cities (40% of all those surveyed). Groundwater alone was used in 5 cities (17%). In 13 cities (43%) both surface and groundwater were used. In some cities, although groundwater is the source, the wells are close to the river, e.g. the Red River in the case of Hanoi.

Most cities in Vietnam have some sewerage and wastewater drainage coverage. Sewerage systems are covered networks but the drains carrying city wastewater may be open. Data show that in larger cities about 75% of the domestic wastewater drains into municipal sewerage systems of some sort, and in the smaller cities this figure is 45%.

Industrial wastewater is sometimes discharged into municipal collection systems when an alternative is not available. Industries close to rivers tend to discharge their wastewater directly into the rivers. There is no discernible pattern in the proportion of industrial wastewater to total wastewater that can be related either to the size of the city or the geographic region (Figs 7.1 and 7.2).

In total, out of 2.7 million m^3/d of fresh water consumption in the 30 cities, 77% returns to nature as wastewater; domestic wastewater constitutes between 60–90% of this.

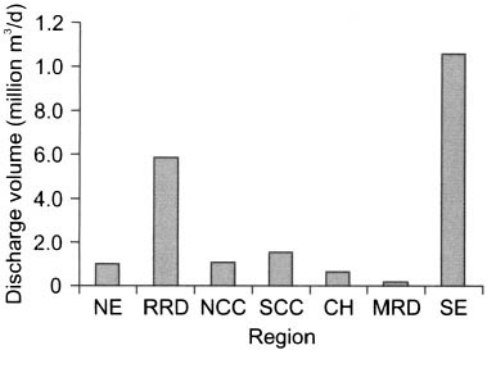

Fig. 7.1. Total wastewater discharge by region in Vietnam. (NE = northeast, RRD = Red River delta, NCC = north central coast, SCC = south central coast, CH = central highland, SE = southeast, MRD = Mekong River delta).

Pattern and extent of wastewater use

In 93% of the surveyed cities (28) wastewater is used for agriculture or aquaculture or both. More cities use wastewater for agriculture (80%) than for aquaculture (63%).

Agricultural land use

According to our definition of target study area, six of the 30 surveyed cities have urban and peri-urban agricultural land areas exceeding 10,000 ha. Three of the four city provinces (Hanoi, Ho Chi Minh, and Hai Phong) have the largest agricultural land areas constituting a high proportion (>45%) of the total land area in each city.

Wastewater agriculture

In the 30 cities surveyed, agricultural land accounts for 35% of the total land area. Wastewater irrigated areas vary from 0.5–5% (average 1.6%) with 70% of the cities falling within the range of 1–2% (Table 7.2).

On a regional basis, the highest proportion of wastewater-irrigated land is in NCC, possibly due to the water scarcity in that area. However, a similar pattern is not observed in SCC, which is also water-scarce but where most of the cities surveyed are coastal either without available agricultural land, or where most wastewater is discharged directly into the sea.

Cropping pattern related to wastewater use

Generally in Vietnam there are three cropping seasons; spring, summer and winter (Fig. 7.3). The predominant crop in both wastewater and non-wastewater areas is paddy rice, also called lowland rice. Rice is grown on 76% of the area in the spring and on 85% in the summer. Vegetables and upland crops (corn, maize, sweet potatoes, groundnut, soybean) are also grown. Wastewater is used markedly less in winter than in other seasons, because paddy rice that requires a lot of water, is not a winter crop.

Reasons for use of wastewater for agriculture

Unlike in many arid and semi-arid countries, where urban wastewater is sought after and used extensively, in Vietnam the underlying reason for its agricultural use is the unplanned

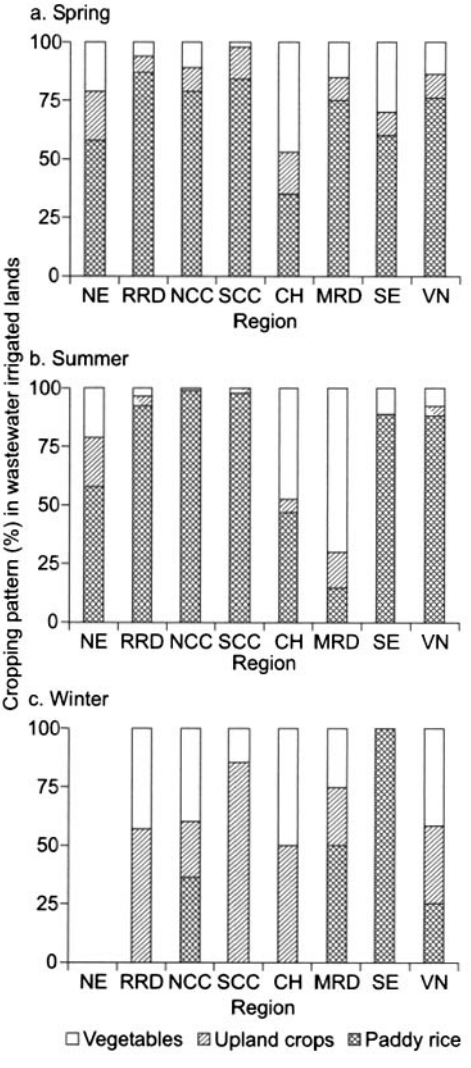

Fig. 7.3. Cropping patterns in wastewater-irrigated areas across regions (see Table 7.1) of Vietnam by season.

Table 7.2. Agricultural land and wastewater-irrigated agriculture by city class in Vietnam (surveyed cities).

City class	Land area (ha)	Agricultural land in city (ha)	Agricultural land as % total land area		Area irrigated with wastewater (ha)	Wastewater-irrigated area as % agricultural land	
			Mean	Range		Mean	Range
I	301,599	140,234	46.5	–	2,561	1.8	1–4
II	397,267	111,798	28.1	8–58	485	0.4	0–4
III	88,172	18,708	21.2	7–40	215	1.1	0.3–3
IV	45,122	25,345	56.1	42–66	1,368	5.4	0–17
V	61,413	17,035	27.7	16–74	243[a]	1.5[a]	0–10
Overall	893,573	313,120	35.0	–	4,871[a]	1.6[a]	–

[a] Excludes Ninh Binh where most of the wastewater used is from a thermal power plant and is therefore not representative.

discharge of wastewater into natural water courses, drainage canals or irrigation canals. However, intentional wastewater use occurs in some instances due to inadequacy of irrigation systems particularly at the tail end. Survey results show that approximately 60% of the cities use wastewater because of its unplanned management that results in discharge into natural watercourses or drainage canals. City officials who were interviewed recognise wastewater's nutrient and water value, but less than 10% of the available wastewater is used. Farmers were not interviewed in this survey, but from the authors' experience in other discussions, farmers value the wastewater particularly for aquaculture. Both officials and farmers are uneasy about using industrial wastewater. Wastewater is generally discharged directly to rivers from riverine cities, taking it away from the metropolitan area.

Nationwide Estimation of Wastewater Agriculture

An attempt was made to extrapolate the data from 30 cities to a national context using city class and regional averages. This approach has its limitations (as seen from Tables 7.3 and 7.4 below) given the wide variation in values within a class or a region.

This extrapolation to the national level gives the following figures for wastewater use in agriculture:

9,410 ha based on class averages,
5,957 ha based on regional averages
6,972 ha (i.e. 446,937 × 1.6% from Table 7.2) based on the overall average

A range of 6,000 to 9,500 ha is indicated as a national figure.

It must be noted that the magnitude of these figures largely depends on the initial definitions

Table 7.3. Nationwide projection of wastewater-irrigated agriculture by city class.

City class	Land area (ha)	Agricultural land in city (ha)	Agricultural land as % of total land area	Wastewater irrigated area (mean) as % agricultural land – based on survey	Calculated wastewater irrigated area (ha)
I	301,599	140,234	46	1.8	2,566
II	416,915	117,573	28	0.4	506
III	168,506	60,634	36	1.1	697
IV	225,617	95,376	42	5.4	5,150
V	147,064	33,118	23	1.5	490
Total	1,259,701	446,937	35		9,410

Table 7.4. Nationwide projection of wastewater-irrigated agriculture by region in Vietnam.

City class	Land area (ha)	Agricultural land in city (ha)	Agricultural land as % of total land area	Wastewater irrigated area (mean) as % agricultural land – based on survey	Calculated wastewater irrigated area (ha)
NE	103,504	24,552	24	2.2	530
RRD	262,248	121,237	46	1.9	2,340
NCC	45,162	15,253	34	4.7	722
SCC	243,192	36,517	15	0.8	299
CH	130,195	29,839	23	1.1	343
MRD	123,996	80,251	65	0.5	369
SE	296,672	132,330	45	1.0	1,284
NW	54,732	6,955	13	1.0	70
Total	1,259,701	446,937	35		5,957

of *target study area*, *wastewater*, and *wastewater-irrigated areas*. This assumes that very little wastewater agriculture takes place outside of the city limits, but this is not so in Vietnam, where the pollution of irrigation canals extends the problems of wastewater irrigation beyond the city boundaries. Furthermore, the proportional method used to calculate the extent of land under wastewater irrigation in schemes served by canals receiving wastewater may have led to an underestimation of the real situation. This confirms the importance of proper definitions and the need for a standard typology if results from different countries are to be compared.

Aquaculture Using Wastewater and the Role of Natural Stabilisation Ponds as Treatment Facilities

Of the 30 cities surveyed, 19 use wastewater for aquaculture. Natural stabilisation ponds, traditionally used for flood inundation control, that are prevalent across the country, are generally used for aquaculture but not exclusively using wastewater. Data were not comprehensive, but from available figures, the annual total fish production from wastewater in the cities surveyed is 6,359 t, of which more than half (3,380 t) comes from Hanoi, by far the largest fish producer using wastewater. Certain districts of Hanoi, e.g. Than Tri and Tu Liem depend almost entirely on wastewater for both agriculture and aquaculture. Five other cities annually produce around 100–200 t. Wastewater aquaculture appears to be more common in the larger cities, i.e. in eight out of the 10 class II cities. Tilapia and carp species predominate.

According to doctors interviewed, it seemed that little information was available in Vietnam about health risks associated with sewage-fed aquaculture (Dalsgaard, 1995).

Of the sample cities, 73% had stabilisation ponds, many of them over 10 ha in size. In many cities, due to the poor collection and disposal infrastructure for wastewater, these ponds serve the additional purpose of bio-treatment. However, the sizing of the ponds does not correspond to the degree of treatment required by the wastewater (Metcalf and Eddy, 1991). Estimates of retention times varied from 1–122 days.

Other than these stabilisation ponds other forms of urban wastewater treatment are virtually non-existent (Ha *et al.*, 2001), but industrial wastewater in some instances undergoes some form of treatment before discharge. The applicability of natural pond systems as a low-cost method for the partial treatment of wastewater for agricultural use may prove useful in other countries, and should be further studied under Vietnamese conditions.

Livelihoods, Health and Environmental Aspects

An attempt was made through this nationwide survey to gather information on the number of households using wastewater as an income source. Data availability was sketchy at this level of assessment, and it was understood that more detailed studies on the livelihoods dimension of wastewater use were needed. In the context of this study livelihoods reflect the number of persons dependent or engaged in wastewater agriculture or aquaculture, using it either as a main or a secondary source of income.

Analysis of available information (Tables 7.5 and 7.6) showed 1% of the population depend on wastewater agriculture as a primary or secondary, but not necessarily sole, income source.

In the CH cities of Buon Ma Thuot and Plei Ku, a higher percentage (5%) of households use wastewater. This may be explained by the very small sizes of plots which allow for more households to cultivate vegetables.

Table 7.5. Livelihoods dependent on wastewater use by city class in Vietnam.

	Number of persons as % of population[a]	
City class	Agriculture	Aquaculture
I	1.0	0.10
II	0.3	0.08
III	5.0	-
IV	0.5	0.03
V	3.6	0.02
Overall	1.0	0.09

[a] The population figure excludes cities where information on households was not available.

Table 7.6. Livelihoods dependent on wastewater use by region in Vietnam.

	Number of persons as % of population[a]	
Region	Agriculture	Aquaculture
NE	–	–
RRD	1.4	0.18
NCC	2.3	0.25
SCC	0.2	0.09
CH	5.0	–
MRD	0.1	0.04
SE	0.4	0.01
Overall	1.0	0.09

[a] The population figure excludes cities where information on households was not available.

The proportion of the population engaged in wastewater aquaculture is only one tenth that of agriculture. In Hanoi however, with an annual fish production of 3,380 t, 0.3% of the population uses wastewater for aquaculture. Dalsgaard (1995) reports that farmers can make a net profit of around US$1,400 through wastewater aquaculture, and employees could earn around US$35/month.

Whilst the figures for both agriculture (1%) and aquaculture (0.1%) may be low in percentage terms, for Vietnam this is equivalent to nearly half a million people. The survey did not attempt to provide exact figures of incomes or the percentage of household income attributable to a wastewater source.

No substantive evaluation of environmental and health impacts was carried out at this stage, but the perceptions of authorities were recorded. Of those interviewed, more than half of the local authorities dealing with wastewater in the surveyed cities were aware of the negative impacts of wastewater use on human health and crops. Local officials based on observation and discussion with farmers, gave importance to such visible medical symptoms as skin irritations, and listed poor crop quality and yields as negative impacts. They stated that they would prefer an alternative water source, but in the meantime, wastewater use did not seem to be actively discouraged, and they did not have plans for developing alternative sources.

Institutions for Wastewater Management

Although a series of legislation and decrees emphasising the State's commitment and outlining the responsibilities for water resources protection and management exists, there is no single fully constituted entity responsible for wastewater management per se in Vietnam.

Prevention and mitigation of negative impacts on the environment are regulated by environmental legislation under the Ministry of Science, Technology and Environment (MOSTE). At the provincial and city level, the Department of Science, Technology and Environment (DOSTE), which reports to the Provincial People's Committee (PPC), is responsible for environmental protection and management [extracted from the 'Law on Environmental Protection' (Vietnamese National Assembly, 1994)].

Operation and management of city sewerage systems is under the authority of the Urban Management and Planning Company (UMPC) by decree. The UMPC is supervised by the Department of Transportation and Public Works, or Department of Construction, but reports to the PPC or to the City People's Committee (CPC). In principle wastewater pipes cannot be connected to the city sewerage systems without the approval of these organisations, and this is subject to toxic substances in wastewater being treated to required standards provided in the legislation [extracted from 'Responsibilities of Ministry of Agriculture and Rural Development (MARD)' (Government of Vietnam, 1999)]. However, these are not always enforced.

The Irrigation and Drainage Management Company (IDMC) manages the ponds and irrigation and drainage canals into which the urban sewerage systems are usually discharged. In cities close to rivers, wastewater is pumped directly into the rivers where possible.

Conclusions and Lessons Learned

Pioneer national assessment

The Vietnam national assessment was conducted to acquire an overview of the importance and significance of wastewater agriculture in terms of extent, agricultural production, and liveli-

hood impacts. Such an overview could contribute to developing appropriate policy and legal frameworks for wastewater use within an integrated water resources management framework for Vietnam. It is the first time that such an assessment to acquire a national perspective has been attempted in any part of the world.

- The assessment showed that 93% of the cities sampled use wastewater for agriculture or aquaculture or both. In larger cities in spite, or because of urbanisation, urban and peri-urban agriculture appears to play a significant role in providing food to urban populations
- Wastewater irrigated areas vary from about 0.5%–5% (average 1.6%) of the total agricultural land in the cities; with 70% of the cities in the range of 1–2%.
- The predominant wastewater crop in Vietnam is paddy rice, grown on 76% of the area in the spring and 85% in the summer seasons
- Extrapolation of these findings to national level gives a range of 6,000–9,500 ha as a national figure for wastewater-irrigated agriculture
- 1% of the urban population derives incomes from wastewater agriculture and 0.1% from wastewater aquaculture. Whilst these figures may be very low in terms of percentage, for Vietnam this represents close to half a million people
- Stabilisation ponds serve the dual purpose of inundation control and *de facto* biotreatment. The latter is not very effective as the ponds were not primarily designed for this purpose. These ponds are also extensively used for aquaculture especially in the larger cities.

It must be noted that the magnitude of these figures largely depends on the initial definitions applied to target study area, wastewater, and wastewater-irrigated area. It assumes that very little wastewater agriculture takes place outside of city limits, which is not necessarily the case in all situations in Vietnam, where the pollution of irrigation canals extends the problems of wastewater irrigation beyond city boundaries. Furthermore, the proportional method used to calculate the extent of land under wastewater irrigation in schemes served by canals receiving wastewater, may have been an underestimation of the real situation.

For all these reasons the importance of developing a typology before proceeding to a global assessment clearly emerges.

Factors for rationalising wastewater use

Another reason for carrying out a national survey was to gain a clearer understanding of the reasons behind the use of wastewater in a national context in order to identify key factors that influence such use. Such information is not only useful for national policy, but also provides more generic information for application at a global level. The survey elicited the following:

- In Vietnam the underlying reason for its agricultural use is the unplanned discharge of wastewater into natural watercourses, drainage canals, or irrigation canals. This is unlike the situation in many arid and semi-arid countries, where urban wastewater is sought after and used extensively for its water and nutrient value. In some water-scarce areas of Vietnam, or under poorly maintained or managed irrigation systems, intentional wastewater use is noted
- 77% of the city's freshwater supply returns as wastewater, of which the domestic content varies between 60 and 90%. These figures provide first estimates of possible wastewater return flows in Vietnam and similar countries in the region
- Data show that in larger cities about 75% of the domestic wastewater drains into municipal sewerage systems of some sort and for the smaller cities this figure is 45%. These figures are indicative of the situation in many similar less-developed countries and could be used as the starting point for global estimates of available 'channelled' wastewater that can be put to other uses
- In riverine and coastal cities, both industrial and domestic wastewater is discharged directly to the rivers or to the sea and is not usually used by farmers
- Rice and vegetable cultivation are the highest consumers of wastewater. Both may have substantial impact on human health particularly the possible presence of heavy metals in wastewater-irrigated rice systems.

Emergence of a typology and its requirements

A key lesson from this survey is the realisation that a more descriptive typology (or a classification of the most common forms of wastewater use in irrigation) is a prerequisite to the global assessment of wastewater agriculture, providing a framework to describe different practices and defining what is included in the assessment. A typology that can effectively capture these characteristics will ensure that those involved in this field are aware of the important differences that exist, and are able to identify where a given research finding, policy instrument or technical intervention will or will not find relevant application (Cornish and Kielen, Chapter 6, this volume; van der Hoek, Chapter 2, this volume).

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8 Wastewater Use in Pakistan: The Cases of Haroonabad and Faisalabad

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Abstract

Untreated wastewater is used for irrigation in over 80% of all Pakistani communities with a population of over 10,000 inhabitants. The absence of a suitable alternative water source, wastewater's high nutrient value, reliability, and its proximity to urban markets are the main reasons for its use. Two case studies in Pakistan studied the impact of untreated wastewater use on health, environment, and income. The results showed a high increase in hookworm infections among wastewater users and a clear over-application of nutrients through wastewater. Heavy metal accumulation in soil over a period of 30 years was minimal in Haroonabad, a small town with no industry, but showed initial signs of excess levels in soil and plant material in Faisalabad, a city with large-scale industry. The impact of wastewater irrigation on household income was considerable as wastewater farmers earned approximately US$300/annum more than farmers using freshwater. Both case studies showed the importance of wastewater irrigation on local livelihoods. The lack of financial resources at municipal and provincial levels for wastewater treatment calls for other measures to reduce the negative impact of untreated wastewater use on health and environment, for example to manage groundwater, regular (canal) irrigation water, and wastewater conjunctively, and regular deworming treatment of those exposed to wastewater.

Introduction

Pakistan has a population of over 140 million and is one of the few countries that is almost completely dependant on a single river system for all its agricultural water demands. The Indus river and its tributaries provide water to over 16 million hectares of land, situated in the mainly arid and semi-arid zones of the country. A rapidly growing population, saline groundwater, a poorly performing irrigation distribution system, and recurrent droughts have led to increased water shortages. Under these conditions, the use of untreated urban wastewater for agriculture has become a common and widespread practice.

Preliminary results from a country-wide survey in the four main provinces showed that untreated wastewater was used in 50 out of 60 visited cities. The three main reasons for the use of wastewater were the high salinity of groundwater, recent droughts that have led to a decline in groundwater tables, and the nutrient value of wastewater. Other important

 Wastewater Use in Irrigated Agriculture (eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

reasons were the proximity of urban markets and the reliability of wastewater, which unlike regular irrigation water is not subjected to a rotational schedule. In more than half of the visited cities some sort of fee was paid by farmers to either the municipality or the local wastewater utility for the use of wastewater. For example, in the city of Quetta, 212 farmers cultivating 800 ha collectively paid US$12,000/annum for the right to use wastewater. This was 2.5 times more than the fee for regular irrigation water. Land rent in all cities reflected the importance of wastewater with the rent for land that had access to wastewater being at least double and in some cases up to six times that of land without access to wastewater. In the city of Quetta, the average annual rent for land with access to wastewater was US$940/ha, compared to US$170/ha for land irrigated by freshwater.

This chapter presents two ongoing case studies in progress since January 2000 in a small town without major industry (Haroonabad) and a large industrialised city (Faisalabad). The objective of both case studies was to study wastewater use in a holistic way, looking at environmental and health risks together with the economic benefits and costs for a household. To this end, a number of study components were implemented including a cross-sectional health survey to estimate the prevalence of intestinal nematode infections among exposed and unexposed farmers, a nutrient and water balance, an evaluation of the irrigation and nutrient application of wastewater irrigation, a soil and crop survey looking at soil and crop heavy metal concentrations and potential human food chain contamination risks, an entomological study looking at the potential of wastewater bodies to support the life cycle of disease transmitting mosquitoes, and an economic survey comparing the income of households with access to wastewater to that of households without access to wastewater. At both sites, the impacts on water quality and heavy metal uptake were studied by examining locations where untreated wastewater was used exclusively, where freshwater and wastewater were mixed, and where freshwater was used exclusively.

Background

Haroonabad

The town of Haroonabad is located on the edge of the Cholistan desert in southern Punjab province, close to the Indian border. In 1998 the population was 63,000 (Population Census Organization, 2001) and apart from the small-scale seasonal, cotton-related industrial activities such as washing and ginning (separation of seeds and fibre), there was no major industry in the town. The arid climate, with an annual average rainfall of 160 mm, potential evaporation of 2500 mm, and temperatures ranging from 0°C in January to 48°C in July, make agriculture without irrigation virtually impossible. Shortly after the construction of a sewerage system in 1965, farmers started using untreated wastewater pumped from the newly constructed disposal station for irrigation. In 1979 more pumps were installed in and around the town to dispose of blocked wastewater, after the sewerage system had collapsed because of heavy monsoon rains. This resulted in the development of more wastewater-irrigated sites. Currently there are three main sites with a total irrigated area of over 130 ha. The main crops grown with wastewater are vegetables (in particular cauliflower) cotton, and fodder.

Faisalabad

The city of Faisalabad has a population of just over 2 million and is the third largest city in Pakistan. Centrally located in the heart of the Punjab province it was founded in 1900 as an agricultural market town, but has since then rapidly developed into a major agro-based industrial centre. Over 150 different industrial units have been identified by the local Water and Sanitation Agency (WASA), most of which are involved in such cotton processing tasks as washing, bleaching, dying and weaving.

The use of wastewater for agriculture was common, a survey showed that at least nine different sites could be identified, differing in size from a few ha to almost 1,000 ha. Two main sites can be distinguished, the Narwala Road

site and the Channel 4 site. Farmers at the first site used wastewater of primarily domestic origin, while farmers at the latter site used a mixture of industrial and domestic wastewater. Common crops at both sites were fodder, wheat, cotton and vegetables (cauliflower, spinach, and aubergine). The aquifer underlying the city was highly saline and could not be used as a source of irrigation or drinking water. Temperatures ranged from 48°C to −4°C, while annual rainfall has varied between 198 mm and 615 mm over the last 40 years.

Water Quality, Crops and Cropping Intensities

Wastewater used for irrigation in Haroonabad and at both sites in Faisalabad (Table 8.1) was not fit for unrestricted irrigation according to microbiological guidelines set by the World Health Organization (WHO) *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture* (WHO, 1989). However, the WHO guidelines state that the guidelines can be relaxed when vegetables are eaten cooked, and in this case, the main vegetables cultivated, cauliflower, spinach and aubergine, are almost exclusively eaten cooked. The high values of electrical conductivity and total nitrogen loads of the wastewater placed medium restrictions on the use of this wastewater for agricultural production as its use could result in limited crop growth and hence yield reductions (Pescod, 1992).

During the course of the studies farmers mentioned that they were limited in their choice of crops, though some crops considered unsuitable by one farmer were grown by another. There seemed to be a consensus among farmers that such root crops as carrots, radishes, onions and potatoes were unsuitable for wastewater irrigation, because as a result of their foul smell, poor colour, and in the case of carrot and radish, the development of several short, not single straight roots, these could not be sold in the local market. The main crops grown were fodder sorghum (*Sorghum bicolor*), cauliflower, spinach, cotton, wheat, tomatoes and aubergine. The number of crops grown on the same land each year on wastewater-irrigated sites in Faisalabad and Haroonabad was three, compared to less than two grown in fields irrigated with freshwater.

Farmers interviewed along the length of Channel 4 encompassing fully, mixed, and

Table 8.1. Water quality parameters of wastewater used for irrigation in Haroonabad and at the Narwala and Channel 4 sites in Faisalabad, Pakistan.

Parameter	Unit	FAO and WHO guidelines	Haroonabad	Faisalabad	
				Narwala Road	Channel 4
Electrical conductivity (EC)	dS/m	< 3	4.4	3.1	5.8
Faecal coliform (FC)	Count/100 ml	1000	6.3×10^7	$>10^8$	$>10^8$
Helminth eggs	Number/l	< 1	100	763	
Sodium adsorption ratio (SAR)		< 9	4.5	6.3	16.9
Total nitrogen (N)	mg/l	< 30	78.3	41.6	35.7
Total phosphorus (P)	mg/l	8.6	6.0	5.7	
Total potassium (K)	mg/l	34.7	20.0	35.1	
Manganese (Mn)	mg/l	0.20	0.07	0.14	
Chromium (Cr)	mg/l	0.10	0.23	0.05	
Lead (Pb)	mg/l	5.0	0.04	0.24	
Nickel (Ni)	mg/l	0.20	0.14	0.03	
Copper (Cu)	mg/l	0.20	0.35	0.09	
Cobalt (Co)	mg/l	0.05	0.06	0.08	
Cadmium (Cd)	mg/l	0.01	0.01	0.00	
Iron (Fe)	mg/l	5.0	0.22	0.16	
Zinc (Zn)	mg/l	2.0	N.D	0.14	

non-Channel 4 water users indicated that 'excess' application of Channel 4 water to wheat and sorghum seedlings less than 30 days after emergence resulted in severe 'burning' of crops and frequently resulted in expensive re-planting. Further, the long-term application of Channel 4 water has resulted in a significant breakdown in soil structure and visible indicators of soil salinity. In addition, the formation of a compact surface layer has resulted in the delayed emergence of both wheat and sorghum. Prior to reliance on Channel 4 water, the emergence time for wheat was 5–7 days. After relying on Channel 4 water for 5–16 years, emergence now takes place after 15 days.

Nutrient and Water Balance

The original research question about water and nutrient use in both Haroonabad and Faisalabad was whether wastewater was applied according to the plants' water and nutrient requirements. At both sites, nutrients were over-applied when compared to fertiliser standards set by the Ministry of Food, Agriculture and Livestock, Federal Water Management Cell (1997). Table 8.2 shows the example of cauliflower irrigated with wastewater in Haroonabad and Faisalabad. The differences in nitrogen ratios (N applied/N recommended) between Haroonabad and Faisalabad can be explained by daily and monthly fluctuations in the quality of wastewater.

The over-application of wastewater was reflected in low irrigation performance, as over-application of wastewater led to high percolation (Ensink *et al.*, 2002). In addition, the nitrogen ratio results for both Haroonabad and Faisalabad, indicated a significant 'inefficient' over-application of nitrogen (Table 8.2). This resulted in high levels of nitrates, nitrites and *Escherichia coli* in groundwater under the wastewater-irrigated sites. These levels of nitrates, nitrites and *E. coli* would be of concern if groundwater were to be used for drinking water purposes [World Health Organization (WHO) *Guidelines for drinking-water quality*] (WHO, 1993) but the natural salinity of this groundwater has prevented such use.

Heavy Metals

Haroonabad

The results for Haroonabad indicate that because the pH of the soils analysed ranged from 7.72–8.30, the levels of copper (Cu), nickel (Ni), lead (Pb), and chromium (Cr) are within European Economic Community (EEC) maximum permissible (MP) levels (Table 8.3). No MP levels are established for cobalt (Co) and manganese (Mn). However, a significant accumulation of Pb and Cu can be observed within the top 0–15 cm of the 100% wastewater-irrigated soil profiles (Table 8.3). In contrast, Ni, Co, Cr and Mn remained relatively uniform irrespective of depth with mean (n=6) concentrations of Ni 30.2 (±0.4), Co 12.3 (±0.5), Cr 56.3 (±9.5) and Mn 256.3 (±18.4) mg/kg (Table 8.3).

As with the 100% wastewater-irrigated field, Pb and Cu levels were elevated at the soil surface (0–5 cm) of the conjunctively irrigated field (Table 8.3). However, the surface accumulation of Pb and Cu was restricted to 0–5 cm soil depth compared to 0–15 cm for the 100% wastewater-irrigated field. It is suggested that the elevated levels of Pb could be attributable

Table 8.2. Total nitrogen (TN) application, nitrogen ratios and total amount of wastewater applied to cauliflower in Haroonabad and Faisalabad, Pakistan.

	TN/cropping season (kg/ha)	Nitrogen ratio[a] (%)	Total water applied (mm)
Haroonabad	546	440	314
Faisalabad	192	160	321

[a] Nitrogen ratio: $\frac{\text{Total N applied}}{\text{Recommended N}} \times 100\%$

Table 8.3. Vertical distribution of heavy metal concentrations in soil (mg/kg) at varying soil depths in relation to type of irrigation water used at three sites in Pakistan.

	Concentration (mg/kg) at various soil depths[a]							
Type of irrigation water	Pb	Pb	Cu	Cu	Ni	Co	Mn	Cr
100% wastewater	(0–15 cm)[a]	(15–90 cm)	(0–15 cm)	(15–90 cm)	(0–90 cm)	(0–90 cm)	(0–90 cm)	(0–90 cm)
	19.4	9.2	86.9	71.1	30.2	12.3	256.3	56.0
	(2.3)[b]	*(1.2)*	*(1.4)*	*(2.4)*	*(0.4)*	*(0.5)*	*(18.4)*	*(9.5)*
Conjunctive use	(0–5 cm)	(5–90 cm)	(0–5 cm)	(5–90 cm)	(0–90 cm)	(0–90 cm)	(0–90 cm)	(0–90 cm)
	13.4	6.4	77.3	58.7	26.9	12.4	231.9	46.5
				(2.0)	*(1.1)*	*(0.9)*	*(12.5)*	*(4.6)*
Freshwater	(0–90 cm)		(0–90 cm)		(0–90 cm)	(0–90 cm)	(0–90 cm)	(0–90 cm)
(Hakra 4/R)	7.9		21.9		22.5	11.2	185.7	64.2
	(1.7)		*(4.4)*		*(3.3)*	*(1.0)*	*(16.1)*	*(11.0)*
EEC MP[c] levels	50–300		50–140		30–75			100–150

[a] Sampling depth in parentheses.

[b] Standard deviation in parentheses and italicised.

[c] The range of European Economic Community (EEC) maximum permissible (MP) levels for Pb, Cu and Ni given in Table 8.3 correspond to soil pH. The lower value given corresponds to a soil pH < 5.5 and the higher value a soil pH >7.0.

to deposition from petrol fumes as the 100% irrigated wastewater site is located next to the central bus station. Other metal concentrations remain relatively uniform with depth with mean (n=6) concentrations of Ni 26.9 (±1.1), Co 12.4 (±0.9), Cr 46.5 (±4.6) and Mn 231.9 (±12.5) mg/kg.

In contrast, both soil Pb and Cu in the Hakra 4/R (freshwater-irrigated) fields were significantly lower than in the wastewater-irrigated plots (Table 8.3). In addition, no surface accumulation of Pb or Cu was observed. In comparison to the wastewater-irrigated plots, levels of Ni, Co, Mn and Cr remained relatively uniform irrespective of soil depth.

Faisalabad

During April–May 2002 soil and wheat samples were collected from pre-selected fields at 1-km intervals along the length of Channel 4 to evaluate the impact of wastewater use on soil heavy metal accumulation. As a control, samples were also collected from fields receiving freshwater irrigation from the Dhudi Wala Minor. The results indicated that for both the Channel 4 and Dhudi Wala Minor irrigated fields, soil Cd, Pb, Zn, Ni, Cr, and Cu concentrations are all below EEC MP levels irrespective of sampling site (Table 8.4). However, elevated levels of Zn were observed at the 0.2 and 1.3 km sampling locations with values of 90.6 mg/kg at 0.2 km and 92.6 mg/kg at 1.3 km. In addition, elevated levels of Cd were observed between the 1–3 km sampling site with a mean Cd value of 0.40 ± 0.03 mg/kg compared to a mean Cd concentration of 0.14 ± 0.04 mg/kg for the 4–9 km sampling site. Lead, Cr, Ni, and Cu concentrations were relatively uniform irrespective of sampling site and irrigation source.

The wheat grain results indicate trace (<0.05 mg/kg) concentrations of Pb, Cr, and Ni in grain, which reflected the relative immobility of these elements in soils and translocation in the plant. Wheat grain Cu and Zn concentrations for both the Channel 4 and Dhudi Wala Minor irrigated fields were at concentrations indicative of optimum yields (Wells *et al.*, 1996). The wheat grain Cd concentrations exceed the Joint FAO/WHO Expert Committee on Food Additives (JECFA) Codex Committee on Food Additives and Contaminants (CCFAC) draft provisional maximum level (ML) for Cd in wheat grain of 0.1 mg/kg (Codex Alimentarius Commission, 2002). However, Chaney *et al.* (1996) suggested that a Cd:Zn ratio of <1.5% effectively provides protection against Cd-induced health impacts. For the Channel 4 and Dhudi Wala Minor wheat samples, the Cd:Zn ratio ranged from 0.28–1.05%. Health risks are therefore effectively prevented at this time.

In summary, with the exception of the surface accumulation of Pb and Cu in 100% wastewater and conjunctively irrigated fields in Haroonabad (Table 8.3) heavy metal accumulation in Haroonabad was of minor concern. However, monitoring programmes should be established and the source of contamination confirmed and managed to prevent soil Cu and Pb reaching levels that may prove toxic to crop growth and soil biological functions. In Faisalabad the source of Cd contamination should be identified and managed, monitoring soil and edible portions of crops is essential to ensure protection of the food chain from elevated levels of Cd.

Health Impact

Intestinal nematodes

Preliminary results from a health survey in Faisalabad and a completed study in Haroonabad (Feenstra *et al.*, 2000) show a similar trend (Table 8.5). Wastewater farmers had a 4 to 5 fold higher risk of hookworm infection than a group of non-wastewater users. There was no difference in risk of hookworm infection between children of wastewater farmers and children of non-wastewater irrigators.

Studies in Mexico identified *Ascaris lumbricoides* as the main source of intestinal nematode infections among wastewater farmers and their children (Blumenthal *et al.*, 2001). Although *A. lumbricoides* eggs were found in large numbers in wastewater, the studies in Faisalabad and Haroonabad showed very low prevalence of *A. lumbricoides* among wastewater farmers and their children for as yet unexplained reasons.

Table 8.4. Soil and wheat grain heavy metal concentrations (mg/kg) in relation to irrigation source, Faisalabad, Pakistan.

Metal	Sample type	Channel 4	Dhudi Wala Minor
Cd	Soil (0–20 cm)	0.23 ± 0.13[a]	0.21 ± 0.00
		(0.08–0.44)[b]	*(0.21–0.21)*
	Wheat grain	0.16 ± 0.04	0.11 ± 0.00
		(0.10–0.23)	*(0.11–0.12)*
Pb	Soil (0–20 cm)	10.5 ± 1.7	11.6 ± 0.1
		(8.5–15.2)	*(11.5–11.6)*
	Wheat grain	Trace < 0.05	Trace < 0.05
Zn	Soil (0–20 cm)	50.8 ± 15.2	44.5 ± 4.8
		(32.1–92.6)	*(41.2–47.9)*
	Wheat grain	28.0 ± 9.4	29.6 ± 4.8
		(15.0–47.9)	*(41.2–47.9)*
Cr	Soil (0–20 cm)	26.3 ± 3.4	24.1 ± 1.8
		(20.7–35.4)	*(22.8–25.4)*
	Wheat grain	Trace < 0.05	Trace < 0.05
Ni	Soil (0–20 cm)	33.8 ± 4.1	35.2 ± 0.98
		(27.1–40.4)	*(34.5–35.9)*
	Wheat grain	Trace < 0.05	Trace < 0.05
Cu	Soil (0–20 cm)	21.6 ± 2.3	22.8 ± 0.09
		(17.18–28.30)	*(22.70–22.83)*
	Wheat grain	6.5 ± 1.1	6.0 ± 0.04
		(5.6–10.2)	*(6.0–6.0)*

[a] Values in mg/kg ± 1 standard deviation.
[b] Range of concentration given in parentheses and italicised.

Vector breeding

Vector studies in Haroonabad and Faisalabad revealed that wastewater stabilisation ponds and other wastewater bodies favoured the breeding of *Anopheles* and *Culex* mosquitoes. Within the wastewater-irrigated zones, each vector species was found to be associated with specific breeding site types and environmental characteristics. The presence of potential vectors of human diseases such as malaria, filariasis, West Nile fever, and Japanese encephalitis indicated that wastewater systems could contribute to vector-borne disease risks in addition to other associated health risks among poor human communities that depend on wastewater use for their livelihoods. However, this potential role of wastewater

Table 8.5. Hookworm prevalence among wastewater-irrigating farmers and their children compared to a group of unexposed farmers, labourers and their children at two locations in Pakistan.

	Hookworm prevalence			95% confidence
	Exposed (%)	Unexposed (%)	Odds ratio	interval
Haroonabad				
Adults	75 (51/68)	41 (48/118)	4.4	2.3–8.5
Children (age <13)	20 (26/130)	21 (55/261)	0.9	0.6–1.6
Faisalabad				
Adults	15 (24/165)	3 (7/243)	5.7	4.9–6.6
Children (age <13)	6 (18/305)	5 (26/478)	1.1	0.7–1.8

stabilisation ponds to serve as breeding sites for mosquito vectors of human disease has received little attention. Poorly managed wastewater treatment ponds have thick emergent vegetation and floating solid waste along their margins. The vegetation and floating waste offer ideal habitats for the breeding of mosquitoes by attracting them to oviposit and also by providing them with protection against predators. The creation of such perennial water bodies close to large urban areas in an arid environment could pose a significant health risk for communities living around such treatment schemes.

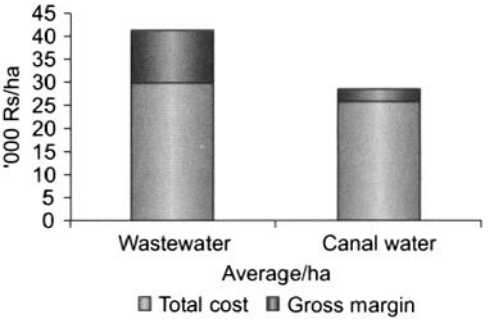

Fig. 8.1. *Total cost and gross margin ('000 Rs/ha) for a wastewater farmer and a regular canal water farmer in Haroonabad, Pakistan (Rs.58 = US$1).*

Household Income and Livelihood

In Haroonabad wastewater farmers spent more money on insecticides, labour and land rent than farmers using regular canal water. The major input cost for regular farmers was for fertiliser and although this was a substantial cost, on average the total costs for regular farmers were less then those for wastewater farmers. However, the average gross margin for a wastewater farmer, about US$173/ha (Rs 10,000/ha), was substantially higher than for a freshwater farmer using canal water, about US$43/ha (Rs 2,500/ha) because of higher cropping intensities and the ability to cultivate crops with higher market values (Fig. 8.1).

Conclusion

Untreated wastewater irrigation poses serious health risks that cannot be ignored. While the risks to consumers may not be excessive, as most vegetables grown in land irrigated with wastewater are eaten cooked, the risks to farmers practicing flood irrigation cannot be ignored. The studies in Faisalabad and Haroonabad show a 5-fold increase in the risk of hookworm infection among wastewater farmers. However many of these farmers have no other option or do not want to use other water. This was illustrated by some farmers in Faisalabad who had access to treated and untreated wastewater but opted for the untreated (black) wastewater as it was considered less saline and better for their crops.

In the present situation there seem to be clear gains for both farmers and municipalities. Farmers are willing to pay high water fees, which in turn are used by municipalities to finance the maintenance and operation costs of drinking water and sewerage services. However, the long-term sustainability is at risk as farmers are limited in their choice of crops and heavy metal uptake by wheat as measured in its grain is getting close to critical levels. Groundwater contamination due to extensive irrigation with wastewater has not been an issue for Faisalabad and Haroonabad because the natural saline groundwater there means they have no alternative irrigation water source, but it would be an important issue in cities and towns in the fresh groundwater regions.

Although the use of wastewater is likely to become increasingly important for Pakistan as a combined strategy for water conservation and pollution prevention, management of this resource is in the hands of local farmers and municipalities. There seems to be little awareness of the risks involved in the use of untreated wastewater among local municipalities where the opinion of many is that 'the farmer knows best'.

It is unlikely that Pakistan will be able to treat all wastewater currently used by farmers up to WHO guideline standards. Enforcement of crop restrictions will deprive many farming families of their livelihoods and there is therefore a need to look at options other than full wastewater treatment or the enforcement of crop restrictions. The need for ways to reduce health and environmental risks while at the

same time safeguarding positive impacts on household income is evident. The WHO guidelines offer such other options as partial treatment for irrigation of vegetables eaten cooked, as is predominately the case here, and the use of deworming medication, which could be appropriate for the economic and environmental situation prevailing in Pakistan. Although these strategies have not been implemented, as full wastewater treatment has always been considered the norm, deworming campaigns, with or without partial wastewater treatment, could potentially be very successful, as they have shown to be in programmes established for school children (UNICEF, 1998).

Encouraging farmers to wear footwear and other protective gear, such as gloves and long trousers, has been suggested as a possible additional measure to protect farmer health. Many farmers might consider footwear and gloves impractical and uncomfortable under field conditions, and therefore the acceptability of such an intervention needs to be investigated prior to its implementation.

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9 Agricultural Use of Untreated Urban Wastewater in Ghana

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Abstract

In Ghana, urban sanitation infrastructure is poor and only a small portion of the (primarily domestic) wastewater is collected for treatment. The bulk ends up in drains and nearby water bodies and is used by urban and peri-urban vegetable farmers for irrigation. Open-space urban and peri-urban vegetable farming is market-oriented and depends on water availability. It not only supports the livelihoods of many farmers and traders but also contributes significantly to the supply of perishable vegetables to cities. However, high contamination levels, especially pathogens, have been recorded in most irrigation water sources as well as on irrigated vegetables. Because wastewater irrigation is illegal, farmers are periodically expelled from their plots. As any significant improvement of the urban sanitation infrastructure is financially constrained, research into strategies for safe wastewater use that considers both health risks and farmers' livelihoods is in progress. The aim is to contribute to the sustainability of urban vegetable production systems and their benefits in West Africa.

Background

Ghana lies at the shores of the Gulf of Guinea in West Africa. To the north, it borders Burkina Faso, Togo to the east and Côte d'Ivoire to the west (Fig. 9.1). It has a population of about 19 million, growing annually at the rate of 2.7%. About 44% of Ghana's total population lives in urban areas. Some urban centres have annual growth rates as high as 6%, more than twice the country's average rate (Ghana Statistical Services, 2002). This includes 'Mega Accra' that encompasses Accra, Tema and Ga districts with 2.7 million inhabitants and Kumasi with 1.0 million inhabitants. The overall national population density is 79 persons/km^2 (Ghana Statistics Services, 2002). Agriculture is the mainstay of the Ghanaian economy, contributing 36% of the gross domestic product (GDP) and employing 60% of Ghana's labour force. The average annual *per capita* income of those employed in agriculture is estimated at US$390.

Annual rainfall ranges from 800 mm in the coastal areas to 2,030 mm in the southwestern rainforests. Table 9.1 summarises climatic conditions in the synoptic stations of Accra (southern belt), Kumasi (middle belt) and Tamale (northern belt) (Agodzo, 1998). The country's surface hydrology comprises three main river basins: the Volta basin that covers about three-quarters of the country's surface, the southwestern and the coastal basin systems.

 Wastewater Use in Irrigated Agriculture (eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

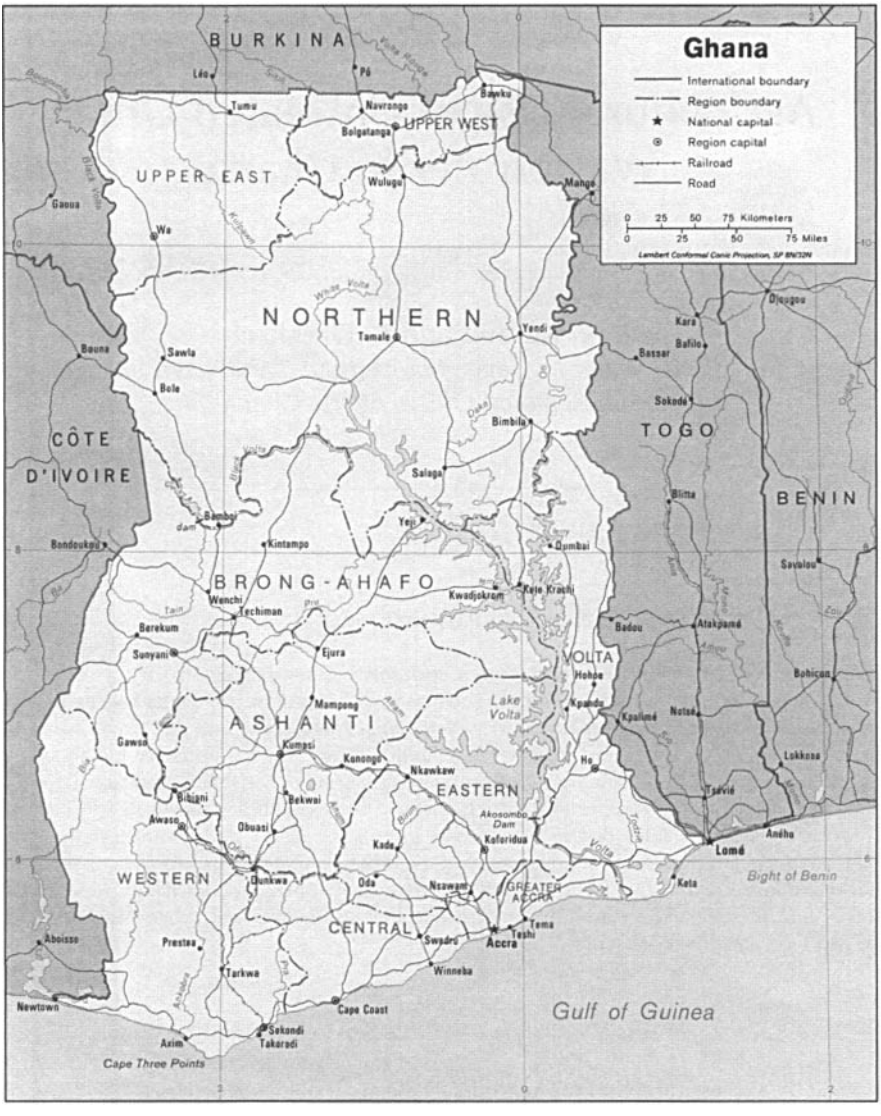

Fig. 9.1. Map of Ghana and its administrative regions.

Status of Urban Wastewater Disposal and Treatment in Ghana

Sanitation and wastewater generation

About 63% of Ghana's population has sanitation coverage, which is more than the West Africa average of 48% (Fig. 9.2) and similar to the average of eastern (62%) and southern Africa (63%) (WHO *et al.*, 2000). While most countries in West Africa (like Senegal) show a very high disparity in provision of sanitation services between rural and urban areas, Ghana has a good balance with 62% coverage in urban areas and 64% in rural areas. According to Agodzo *et al.* (2003) the total amount of grey and black wastewater currently produced annually in urban Ghana has been estimated as 280 million m^3. This wastewater is derived mainly from domestic sources as Ghana's industrial development is concentrated along the coastline where wastewater, treated or

Table 9.1. Mean annual climate data of Accra, Kumasi, Tamale.

Location	Rainfall (mm)	Temperature (°C)	Relative humidity (%)	Sunshine duration (hours)	Wind velocity (km/day)	Solar radiation (MJ/m²/day)	Potential evaporation (mm)
Accra	810	27.1	81	6.5	251	18.6	1,504
Kumasi	1,420	26.1	77	5.4	133	17.0	1,357
Tamale	1,033	28.1	61	7.3	138	19.6	1,720

Source: Agodzo, 1998.

untreated, is disposed of into the ocean. In Ghana, collection and disposal of domestic wastewater is done using:

- Underground tanks such as septic tanks and aqua-privies, either at industrial facilities or at the community level and then transported by desludging tankers to treatment works or dumping sites
- Sewerage systems
- Public toilets
- Pit and improved latrines.

Less than 5% of the households in Accra and Kumasi are connected to piped sewerage systems, while 21% use floodwater drains (gutters) as open sewerage that ends up in nearby water bodies. Some of the urban dwellers discharge their faecal waste into septic tanks while kitchen and other wastes from the home are usually directed into the nearest open drain. As the majority of the urban drains are open, they often serve as defecating areas for households that do not have adequate sanitation facilities. According to the national population and housing census carried out in 2000, one third of all households in Ghana use public toilets, reflecting the absence of toilet facilities in many dwelling places. Pit latrines continue to be used in 22% of all households but an improved version, the Kumasi Ventilated Improved Pit (KVIP), is being promoted and its use is expected to rise from the current 7%. Bucket latrines (4%) are being phased out because they are not hygienic. It is quite striking that more than 25% of all households in Ghana have no toilet facilities, with numbers increasing to about 70% in the three northern regions. Water closets (WCs), considered to be modern toilet facilities, are used by only 9% of the households, most of them located in Accra and Kumasi.

Thus, the majority of the population in urban Ghana does not have appropriate means to manage wastewater and the costs of putting in place the required infrastructure to effectively collect and dispose of all urban wastewater are excessive.

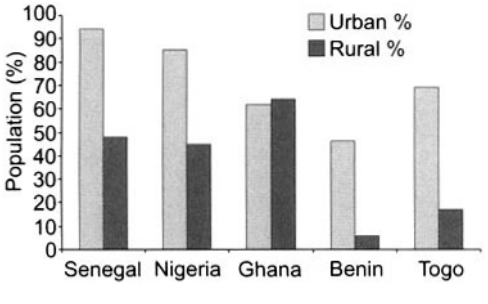

Fig. 9.2. Regional sanitation coverage in five West African countries.
Source: Adapted from WHO *et al.*, 2000.

Wastewater Treatment

More than half of all wastewater treatment plants in Ghana are in and around Accra (EPA, 2001). Two administrative regions (Brong Ahafo and Upper West, Fig. 9.1) have no treatment plant, despite having several important cities and towns. But even where treatment plants are available, less than 25% (primarily in the Greater Accra, Ashanti and Eastern regions, and mostly small-capacity and/or privately owned plants) are functional (Fig. 9.3).

A few years ago, a large modern biological treatment plant started operation at Accra's Korle Lagoon; but, it handles only about 8% of Accra's inner-city wastewater from domestic and industrial sources. The system has a capacity three times greater than that it currently uses, but is constrained by the small urban sewerage network. Only about 10% of the Accra's wastewater is collected for some kind of treatment.

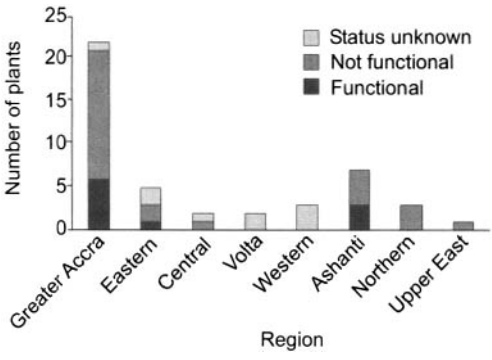

Fig. 9.3. Status of wastewater treatment plants in Ghana. Source: Adapted from EPA, 2001.

Equally disastrous is the situation of septage and night soil treatment. There are only a few low-capacity treatment facilities (usually stabilisation ponds) functioning in most cities. To cite just a few examples: Over the last few years, Kumasi's main faecal sludge treatment plant was receiving an average of 180–500 m^3/day, which is less than 5% of the total faecal sludge produced in the city. The Waste Management Department attributes this low percentage mainly to vehicle breakdowns. However, the treatment ponds have been filled beyond capacity for years, often without desludging for many months and with faecal sludge overflowing to nearby rivers without treatment. The situation is similar in Accra with two sites loaded beyond capacity. The ocean is the third semi-official site, receiving about 40% of the excreta produced in the city. In Tamale, the first plant is still under construction while faecal sludge continues to be dumped in natural depressions.

In Kumasi, a new plant has been built at Buobai, but it can only handle 200 m^3/day and is already reaching its limit. Another pond facility is in preparation near a new landfill site. It is apparent that city sanitation services cannot keep pace with the high urbanisation rates (Keraita *et al.*, 2003b). The general situation causes the authorities concern as shown in Kumasi's 1996–2005 Sanitation Strategic Plan (Box 9.1).

Quality of Irrigation Water Used in Farming

Wherever space allows, urban and peri-urban agriculture take advantage of any water source, be it polluted or not, for dry-season or annual irrigated farming. As most of the wastewater is of domestic origin, faecal coliforms are the contaminants of primary concern. Heavy metal levels in water bodies in and around Ghana's urban centres are not elevated (McGregor *et al.*, 2001; Mensah *et al.*, 2001; Cornish *et al.*, 1999). These studies also showed that inter-seasonal variations of water quality especially after the first heavy rains can be high, hence the need for long-term monitoring.

The main focus of the on-going water quality monitoring by the International Water Management Institute (IWMI) has therefore been on nutrients and microbiological contaminants in irrigation water sources, which in most cases exceed the WHO guidelines significantly (Keraita *et al.*, 2003b). In Kumasi, faecal coliforms typically reach values of 10^6–10^8/100 ml while total coliform levels often range from 10^8–10^{10}/100 ml. Lower faecal

Box 9.1.

The current system of human waste management in Kumasi is inadequate; waste removed from the public and bucket latrines ends up in nearby streams and in vacant lots within the city limits creating an unhealthy environment. Many government offices, schools and private institutions require improved sanitation facilities. Industrial effluent from the breweries, leachate from sawmills and waste oil spillage from the vehicle repair complex at Suame are also discharged into receiving waters without treatment. The stormwater drainage system is essentially an open sewer, which discharges into the Subin, Aboabo and Sissai rivers, and as a result the beneficial uses of these rivers (domestic water supply, irrigation, livestock watering and recreational activities) are adversely affected for a number of miles downstream.'

Source: Waste Management Department, 1996–2005 Sanitation Strategic Plan, Kumasi, Ghana.

coliform counts of 10^4–10^6/100 ml were measured at some urban farming sites in Accra and Tamale. At one site in Accra piped water is available for irrigation; at another, water from a small treatment pond[1] is used. In Tamale water from a broken sewage treatment plant is used for irrigation.

The use of polluted irrigation water threatens public health. Market surveys by IWMI in Kumasi, Accra and Tamale showed that it is very difficult to find any irrigated vegetables (e.g. lettuce, spring onions, cabbage) that are not contaminated with faecal coliforms. Helminth eggs are also commonly found on such vegetables. Coliform contamination levels of vegetables are often almost the equivalent of a similar amount of fresh faeces (Keraita *et al.*, 2003b). The nutrient concentration in the water is comparatively less excessive due to wastewater dilution. In and around Kumasi, for example, the total nitrogen applied via 1,000 mm of annual irrigation ranges between between 10 and 15 kg/ha upstream of the city and up to ten times that value downstream. Phosphorus values range between 7–11 kg P_2O_5/ha. Potassium ranges between 50 and 80 kg K_2O/ha. Salinity is low (EC <1 dS/m) and pH ranges from 6.8–7.2, which is in the normal range for irrigation (IWMI, unpublished).

Use of Polluted Water in Urban Agriculture

It was estimated that if only 10% of the 280 million m^3 of wastewater from urban Ghana could be (treated and) used for irrigation, the total area that could be irrigated with wastewater alone could be up to 4,600 ha. At an average dry-season farm size of 0.5 ha, this could provide livelihood support for about 9,200 farmers in the peri-urban areas of Ghana (Agodzo *et al.*, 2003). However, as described in the previous sections, there is inadequate sewage conveyance capacity. In Accra, as in the other cities directly located on the coast, most wastewater flows into the ocean for lack of any land physically available for agriculture. In other cities and towns, such as Kumasi, wastewater flows from drains into streams, which are usually used for irrigation. Thus wastewater is mostly used in a diluted form mixed with surface runoff and/or stream water (Cornish *et al.*, 2001).

However, there are also cases where farmers use wastewater directly from drains and broken sewers without further dilution, especially in the dry season. For simplification, all these water sources are referred to as 'wastewater' in the following sections, unless a differentiation is required.

Open-space Vegetable Farming

A common picture in both urban and peri-urban areas of Ghana is the cultivation of such cereals as maize in the rainy seasons and of irrigated vegetables in the dry seasons. More than 15 kinds of vegetables are cultivated, all of which are sold. The most perishable (often non-traditional) vegetables, such as lettuce, are usually grown in the city and often harvested 11 times during the year (with only supplementary irrigation during the rainy season) (Table 9.2). Less-perishable vegetables, such as aubergines (locally known as garden eggs) are typical of dry-season irrigation in peri-urban areas. Here, staples like maize and cassava for subsistence are preferred in the rainy season.

Due to the high food prices in the dry season, the highest-value land sites have access to water. They are located on river banks, next to drains, in valley bottomlands, and if possible close to the city to reduce transport costs.

The use of polluted water for vegetable farming is more widespread in the more populated cities where safe water is scare and is used for domestic purposes. From a general survey among open-space farmers carried out in 2002, it was found that about 84% of nearly 800 farmers farming in and close to Accra and almost all 700 farmers in Tamale used polluted water for irrigation, at least during the dry seasons.

Typical urban farm sizes range from 0.1–0.2 ha and they increase in size along the urban–

[1] This is the only site in the country where 'treated' wastewater is used by six farmers. The quality of the water, however, is not much different from other (polluted) sources.

Table 9.2. Features of selected open-space urban agriculture sites in Accra.

Location in Accra (local name)	Farmers (number)	Irrigated area (ha)	Soils	Sources and quality of water	Crops	Marketing
Marine Drive (Independence Square)	98	4	Clay, gravel	Drain water, FC<10^{6-7}/100 ml); Irrigation with watering cans	Lettuce, green pepper, spring onion, cucumber etc.	Farm gate (trader buys crops bedwise on the farm)
Dzorwulu/ Power line, Plant Pool	180	18	Clay, gravel	Water from river Onyasia (FC<10^{5-6}); irrigation with watering cans; in part pipe water (FC<10^{1}); irrigation with drag hose or watering cans	Lettuce, cucumber, cabbage, cauliflower, onion, Chinese cabbage, spring onions, radish, spinach etc.	Farm gate
Korle Bu Hospital	80	10	Clay, sandy soil	Drain water; shallow wells; irrigation with watering cans (FC<10^{8})	Lettuce, cabbage, spring onions, local vegetables (*ayoyo*, *aleefi*), beans etc.	Farm gate
La Fulani	111	65	Sandy clay, clay	Water from stream (FC<10^{6}); furrow irrigation, on a small site water from a military camp treatment pond (FC<10^{6})	Water melon, tomatoes, pepper, bean, okra, lettuce, spring onions, green pepper etc.	Farm gate

rural gradient. As production is market-oriented, farming is input- and output-intensive, particularly in terms of the use of water and such other farm inputs as poultry manure, pesticides and fertilisers. In Ghana, most farmers use watering cans to irrigate, while motor pumps are more common in Togo (Keraita *et al.*, 2003a). Only a few farmers with larger holdings in peri-urban areas use motor pumps. The promotion of treadle pumps started only very recently. Farmers fall into different age groups, but the majority are between 20 and 40 years old. Most of those engaged in urban agriculture are migrants from rural areas, often from the Islamic northern regions, and have experience in farming. For many urban or peri-urban farmers agriculture is the main source of household income, although not the only one.

In contrast to vegetable farmers, almost all crop and vegetable sellers are women. Many of them buy vegetables on-farm from field beds and often order in advance (Danso and Drechsel, 2003). Otherwise, open-space vegetable farming is more than 90% male-dominated especially in urban areas, usually with a large distance between the home and the actual farm plot. The reasons mentioned by farmers of both genders for the dominance of men in vegetable production, are the arduous tasks including irrigation with two heavy 15-l watering cans and traditional work sharing with women responsible for food preparation, small businesses and/or hawking. As one moves to the rural areas, however, the number of women assisting in vegetable farming increases slightly. Most undertake such activities as carrying irrigation water in buckets as 'head-loads' to

the fields, weeding, and harvesting delicate vegetables. While almost all men do vegetable farming purely to generate income, women also use the produce (except for non-traditional crops) to feed their families.

Irrigation Water Requirements and Application Rates

The amount of irrigation water required depends on the effectiveness of rainfall in any given location. For the vegetables grown, the crop water requirements range between 300 and 700 mm depending on the climatic conditions and the season of the crop at the location (Table 9.3). For some farming activities that coincide with the major rainy season, irrigation water requirements are minimal. On the other hand, in the drier months in urban areas located in the dry savannah areas, irrigation water requirements per growing season could be as high as 600 mm as shown in Table 9.3. For farmers in the urban centres that depend on water from the drains, there may be insufficient water to meet their crop requirements (Agodzo *et al.*, 2003), especially if crops are grown all year round. Tap water is only available on one open-space site in Accra (Table 9.2). With up to 11 lettuce harvests per year (manual) application rates between 600 and 1,600 mm are common.

Socio-economic Benefits of Wastewater Irrigation

Individual benefits

Preliminary cost/benefit analyses have been carried out for urban and peri-urban vegetable farmers in and around Kumasi (Danso *et al.*, 2002a; Cornish and Aidoo, 2000). Year-round, open-space urban farmers can achieve annual income levels of US$400–800/ha (Table 9.4). These levels are achieved due to the intensive nature of farming made possible partly by the free and reliable supply of water. However, being successful in this way requires careful observations of market demand in the lean season in order to properly plan for the required inputs, particularly seed (Danso and Drechsel, 2003). Also, dry season peri-urban vegetable farming is seen as a significant source for income generation, since during the wet season staple crops are also grown for household consumption.

Table 9.3. *Crop water requirements for seasonal vegetable production in and around Accra, Kumasi and Tamale.*

Location	Crop	Cropping season	Crop water requirements (mm)	Irrigation water requirements (mm)
Accra	Tomato	Jul – Nov/Dec	527	327
	Pepper	Sep – Dec/Jan	464	325
	Okra	Mar – Jun/Jul	367	23
	Aubergine	Sep – Dec/Jan	508	364
Kumasi	Okra	Dec – Mar/Apr	568	504
	Aubergine	Jan – Apr/Jul	521	140
	Water melon	Dec – Feb/Mar	298	166
Tamale	Tomato	Oct – Jan/Feb	668	604
	Onion	Nov – Feb/Mar	678	581
	Okra	Nov – Feb/Mar	487	450
	Cabbage	Oct – Jan/Feb	590	na

Source: Agodzo *et al.* (2003). The data presented are for irrigation projects near each city.

Table 9.4. Revenue generated in different farming systems.

Farming system	Typical farm size (ha)	Net annual revenue (US$/ha)	Net annual revenue (US$/actual farm size)
Rainfed maize or maize and cassava	0.5–0.9	350–550	200–450
Dry-season vegetable irrigation only: aubergine, pepper, okra, cabbage, etc.	0.4–0.8	300–350	140–170
Dry-season, irrigated vegetables and rainfed maize	0.7–1.0	500–700	300–500
All-year-round irrigated vegetable farming lettuce, cabbage, spring onions, etc.	0.1–0.2	2,000–8,000	100–800

Source: Danso *et al.* (2002a).

A detailed survey carried out by Cornish and Aidoo (2000) in peri-urban Kumasi showed the profitability of different crops (Table 9.5). Based on actual farm size, average profits ranged in villages between US$140–170 per farmer. Irrigation practised here is either manual (watering can) or by motorised pumping. Farmers with motor pumps have higher production costs, but revenues were not commensurately higher (Cornish *et al.*, 2001). If the daily *per capita* income is calculated, only households engaged in urban agriculture (see Table 9.4) could move above the poverty line of US$1 per day (Danso *et al.*, 2002a).

On average, farm income from all vegetables amounts to about US$1,440/ha but a more conservative estimate considering actual crop mix could be US$500/ha (Cornish *et al.*, 2001). Most of the vegetable crops are grown in the dry months of November to February. The authors estimate the actual peri-urban area under informal irrigation within a 40-km radius of Kumasi as 11,500 ha. This is more than the total area reported under formal irrigation in the whole country. The annual value of this production has been estimated as US$5.7 million. A significant part of this (downstream of Kumasi) is produced with wastewater.

As mentioned above, vegetable marketing is the exclusive domain of women, be it in big markets or kiosks in residential areas. Inner urban area production means not only fresh produce but also lower transportation costs and higher profits.

Table 9.5. Income per commodity in peri-urban Kumasi.

Crop	Average crop area/ farmer (ha)	Total crop area (ha)	Total income (US$)	Average income (US$/ha)
Cabbage	0.35	18.5	83,954	4,551
Carrot	0.24	2.9	4,671	1,614
Aubergine	0.47	84.1	135,018	1,606
Cucumber	0.23	4.7	7,169	1,539
Tomato	0.51	99.3	133,324	1,343
Hot pepper	0.49	55.6	69,049	1,242
Okra	0.51	77.7	94,681	1,219
Green bean	0.19	1.7	1,585	948
Onion	0.29	2.0	1,813	896
Water melon	0.81	4.1	3,388	837
Green pepper	0.21	3.5	2,607	743
Ayoyo	0.51	5.1	1,061	210
Lettuce	1.03	16.4	2,705	165
Spring onion	0.19	1.1	174	153
Total		376.5	541,198	

Source: Cornish and Aidoo (2000).

Aggregate Benefit to the City

The value of wastewater irrigation should not only be seen from the perspective of livelihood support, employment, and income generation given that the actual (sometimes small) numbers of open-space farmers might not attract the attention of municipal authorities. The overall (aggregate) benefit to the city should also be highlighted. An example is the dependence of the city on irrigated urban vegetable production. Due to the lack of refrigerated transport and storage, the supply of perishable vegetables to urban dwellers depends significantly on this kind of agriculture (Nugent, 2000; Smith, 2002). In Senegal, for example, about 60% of the vegetables consumed in Dakar are produced within or close to the city (Niang *et al.*, 2002), mostly with wastewater. The specific contribution of urban agriculture to aggregate city supply and its complementarity to peri-urban and rural production has also been quantified for selected cities of Ghana and Burkina Faso (Cofie and Drechsel, 2004). The analysis, that excludes backyard subsistence production, revealed that urban agriculture is a crucial supplier of the most perishable vegetables to the cities' markets. Peri-urban production appears to be an important supplier of tomatoes and aubergines, while the majority of common staple crops like cassava, plantain, maize and rice in the city markets derive from rural areas or are imported (Fig. 9.4).

There is high demand for urban produce especially from low-income households and the large number of small (street) eating places (locally known as 'chop-bars') because it is fresh and they have limited possibilities for storage. Thus, most of the chop-bars benefit from wastewater irrigation.

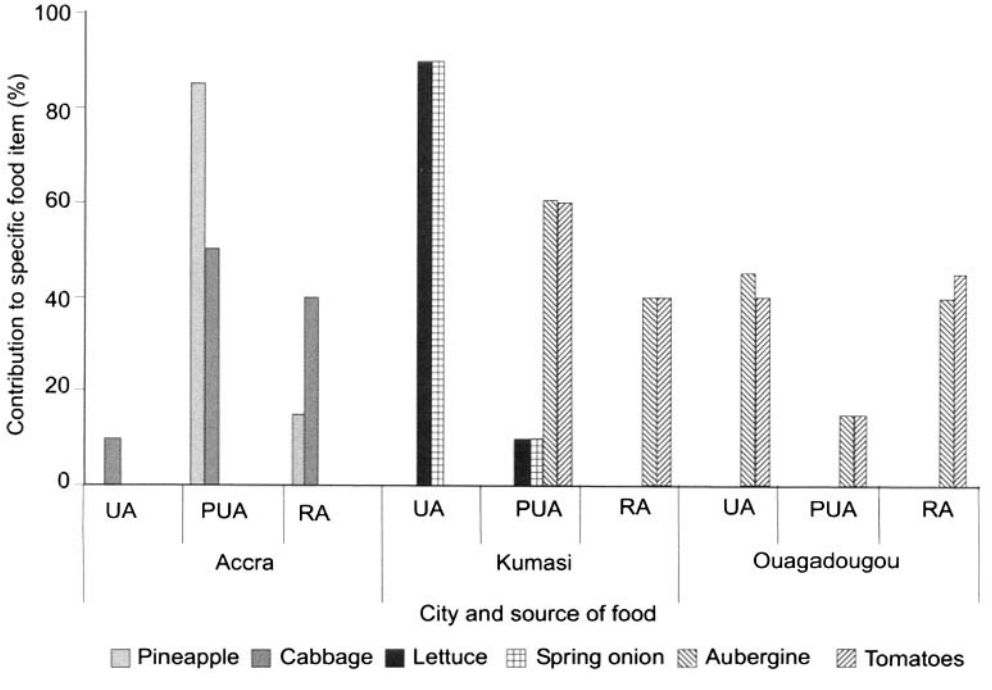

Fig. 9.4. Contribution of urban (UA), peri-urban (PUA) and rural (RA) agriculture to urban vegetable supply in three West African cities.

Source: Cofie and Drechsel, 2004.

Institutional and Perceptional Issues on Wastewater Use in Urban Agriculture

According to one of its bylaws the Accra Municipality allows the production of crops in the city. In contrast to backyard farming, open-space production (or livestock keeping) requires registration with the Medical Officer of Health. Also the Land Title Registration Law accommodates the notion of multiple rights and interests on a single plot, which provides a legal framework for urban agriculture although a distinct corresponding land-use policy does not yet exist (Flynn-Dapaah, 2002). However, as a result of Ghana's decentralisation efforts, there is a Directorate of Food and Agriculture within all metropolitan assemblies. The corresponding Metropolitan Directors of Agriculture work at the interface between the Municipality and the Ministry of Food and Agriculture with their own extension service. During Ghana's annual 'Farmers Day' celebrations they honour – like their rural colleagues – the best farmers from all administrative districts and regions, including the best Metropolitan and peri-urban farmers. All this supports the status of urban agriculture in Ghana. Despite these positive signs the problem of crop contamination raises significant concerns, not only among the health directorates of the same assemblies, but also in the media. This is supported by a municipal bylaw stating, 'No crops shall be watered by the effluent from a drain from any premises or any surface water from a drain which is fed by water from a street drainage'. This bylaw targets those vegetables and fruits likely to be eaten raw (Local Government, 1995). Although authorities expel farmers from time to time, water analysis is expensive and bylaw enforcement weak. Thus irrigated urban agriculture remains informal without any cross-sectoral support by authorities. And as farmers at most locations have no alternative to polluted water, they continue to use it. The interviews also showed that farmers in general place lower priority on the possible nutrient value of the wastewater than on its value simply as a reliable water source, especially in the dry season.[2] Thus the amounts of manure and fertiliser applied to crops are not reduced, even where water is highly polluted. A similar picture has been found with respect to farmers' awareness of pathogen contamination. Cornish and Aidoo (2000) found that only one in four peri-urban farmers would not drink the water he/she used for irrigation. Urban farmers are more often confronted by authorities (and researchers) with the water–health problem and are decreasingly willing to discuss the issue. In general, however, they do not perceive it as a major problem. Those who speak freely usually say that they see no harm in the practice. As one put it, "Ever since I was born, my father has been doing this work and it is the same drain water we have been using with no health problem" (Obuobie, 2003). In fact, the source of the water or its quality is of little concern. More important to the farmers is its uninterrupted availability and that they do not have to pay for it (Obuobie, 2003). A similar low level of concern is found for the use of pesticides, which are usually considered as 'plant medicine'. The most acutely perceived problems are access to credit, markets and water supply in peri-urban areas (Cornish and Lawrence, 2001), as well as land and water access, seed availability and low farm-gate prices in urban agriculture.

As consumers do not ask for 'safe' but 'fresh' and 'clean' products, neat appearance of the crops is most important for sellers. Refreshing and cleaning vegetables with water often of as bad quality as irrigation water is thus normal practice in markets (Drechsel *et al.*, 2000). As mentioned above, many vegetable sellers in the city buy their crops on urban farms and are often aware of the water source, but also prefer not to discuss it, particularly not with customers. The general awareness level for environmental and health issues is low (Danso *et al.*, 2002b) or of less importance than other concerns affecting consumers' livelihood and health (food security, malaria, etc.). When complaints about vegetable appearance were raised by expatriates, however, sellers tried to satisfy customer demand by extra cleaning efforts (Drechsel *et al.*, 2000).

[2] In other places, e.g. Nairobi, farmers showed more awareness of the nutrient value of wastewater (authors' observations).

Conclusions

As in other principal urban centres in developing countries, the sanitation infrastructure in Ghana's main cities has been outpaced by population increases, making the management of urban wastewater ineffective. Large volumes of partially or untreated wastewater adversely affect both water bodies and the urban and peri-urban farmers using these water bodies as sources of irrigation. High levels of pollution, specifically microbiological contamination, have been measured in irrigation water and on crops. This has raised concerns, especially on the part of local authorities as they pose heath risks to farmers and the general public. In order to protect consumers from contaminated vegetables, authorities in Accra have banned the agricultural use of polluted irrigation water. Enforcement, however, would not only affect the livelihoods of urban farmers and vegetables traders but would also reduce the continuous supply of traditional and non-traditional vegetables in the city. In this context, the implementation of the WHO irrigation guidelines appears impossible, as improved water treatment appears unviable. Similarly, there are few (tenure) possibilities or market incentives for farmers to grow crops that are not easily contaminated (like tree crops) or to use, for example, drip irrigation. In view of this, other approaches which take into account both public health risks and farmers' livelihoods need to be devised (Drechsel *et al.*, 2002). These should focus on low-cost options for risk reduction not only on farms (mini-sedimentation ponds, water filters), but also in markets and especially in households. Unless wastewater collection and treatment are generally improved, stakeholder education through awareness campaigns, e.g. on the importance of washing vegetables carefully before consumption will remain crucial to addressing the problem.[3]

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10 Untreated Wastewater Use in Market Gardens: A Case Study of Dakar, Senegal

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Abstract

Urban vegetable production in Dakar plays a significant role in fighting poverty, as it provides both income to farmers, and a source of nutritious food for the poor. However, the irrigation of these crops is cause for concern, as many farmers prefer untreated wastewater to freshwater due to the higher profits stemming from its greater availability, reduced fertiliser costs, and higher yields and production. While using such water, few take precautions to protect their health, and 60% are infected with intestinal parasites. The practice also poses a risk to public health, as three of the main crops produced (lettuce, tomatoes, and onions) are often or exclusively eaten raw. Thus, while there is a growing willingness among policy-makers to encourage urban agriculture (UA), there is also the recognition that current irrigation practices are unsafe. Authorities looking to decentralise wastewater treatment need reassurance that community-level systems can be proven efficient and sustainable. It is recommended that action research be conducted that includes finding effective treatment systems, and that tests the feasibility of other management options such as increasing public awareness, using safer irrigation methods, and practising restricted irrigation. Additional research on the economic importance of UA is also necessary to encourage donors to fund research and development initiatives. Ultimately, action must be taken soon, or a repeat of the 1987 typhoid epidemic in Dakar could lead to backlash among consumers and policy-makers, with devastating consequences for both poor farmers and poor consumers.

Introduction

Senegal ranks 156th out of 175 countries on the United Nations Human Development Index (UNDP, 2003), although its per capita gross domestic product (GDP) is US$1,500. Measures taken in 1994 to liberalise the economy, including currency devaluation and elimination of subsidies, have attracted investment and stimulated economic growth, but have also hit the poor hard. Real wages have declined, and a quarter of the population lives below the internationally recognised poverty line of US$1/day.

Furthermore, recent droughts have decreased the production of groundnuts, an important commodity that uses 40% of the cultivated land, employs 1.5 million farmers and makes up 10% of Senegal's export earnings. The sector saw significant declines in the 1990s until 1999–2000, when it bounced back.

 Wastewater Use in Irrigated Agriculture (eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

On average, Senegal receives 1400 mm annual rainfall but during the 1980s, rainfall declined significantly before stabilising in recent years (Gommes and Petrassi, 1996). The south receives more rainfall than the north, where only about 300 mm fall each year. The city of Dakar receives about 450 mm rainfall each year (RADI, 2002). However, 80% of this is concentrated in 4 months – July to October.

All of these factors – removal of subsidies on basic foodstuffs, unemployment arising from low commodity prices, and recent droughts – have threatened the food security of the poor. Poor rural migrants looking for work increasingly find themselves in Dakar, the largest city with a population of 1.9 million people, and the centre of economic power. With a growth rate of 4%, Dakar's population is expected to reach 3.8 million by 2015. Although 80% of Senegal's industry is located in Dakar (RADI, 2002), the city still has a 25% unemployment rate. Thus, to generate income and food, more and more people have set up market vegetable gardens, which provide income, and fresh, nutritious food for the urban poor. Because it is often more convenient, reliable, and profitable, many farmers use untreated wastewater for irrigation.

Since 1999, the International Development Research Centre (IDRC) has supported Environnement et Dévéloppement–Tiers Monde (ENDA) and the Institut Fondamental de l'Afrique Noire (IFAN) to study wastewater use and urban agriculture in Dakar. IDRC first supported pilot research to identify which types of natural wastewater treatment systems would work best in Dakar. A second phase of the research project, upon which this case study is based, focused on developing two community-scale wastewater treatment plants, and a better understanding of the nature and impacts of urban gardening in Dakar. The team used GIS and aerial photos to outline the extent of UA in Dakar. For the entire production cycle, from on-site field plots to transport to the markets, the team gathered data using surveys including individual interviews and focus group discussions. Fifty farmers on three different sites were surveyed. Samples of UA produce, human waste (stool, urine) and blood of farmers were taken to assess health impacts. The study encompassed all three seasons in Dakar and analysed sites using groundwater (as a control) and untreated wastewater to make comparisons. The research results are presented in this chapter, which first describes the nature and extent of urban farming in Dakar and then outlines its health and environmental effects. This is followed by an analysis of the socio-economic factors involved, a description of the institutional and legal context, and a breakdown of other constraints to production. Finally, management and policy recommendations are outlined, and future research needs are identified.

Urban Agriculture in Dakar

Location, size, principal crops

Vegetable production in Senegal centres on the *Niayes* – shown in Fig. 10.1, a long, narrow fertile zone of land that stretches 250 km along the coast from Dakar to St. Louis. Its annual output is more than 100,000 t, worth US$18 million, and accounting for 80% of the country's total vegetable production (Touré Fall and Salam Fall, 2001).

As shown in Fig. 10.2, within Dakar there are several major sites where urban gardening takes place. This study focused on the urban farmers in Pikine, which, with a total area around 650 ha, constitutes the largest urban agriculture site in or around Dakar. Known as *les poumons de la ville* (the lungs of the city), this large green space exists within the city as a result of policies first implemented by Leopold Sedar Senghor, the first president of Senegal. Despite its importance, the zone is threatened by both urban development and saline intrusion, and has shrunk by 56 ha (10%) over the last 30 years.

The primary crops grown are lettuce, tomatoes, onions and eggplant or aubergine. While some fruits are cultivated, vegetables are preferred because they grow faster and are more profitable. The total annual production is 39,000 t and constitutes 60% of the vegetables consumed in the city (ENDA–IFAN, 2002).

Of the vegetable plots in Dakar, 80% cover between 0.01 ha and 0.1 ha with an average of 0.05 ha, or 500 m^2. These smallholder plots are traditionally farmed using such hand tools as pitchforks, hoes and shovels (Touré Fall and Salam Fall, 2001).

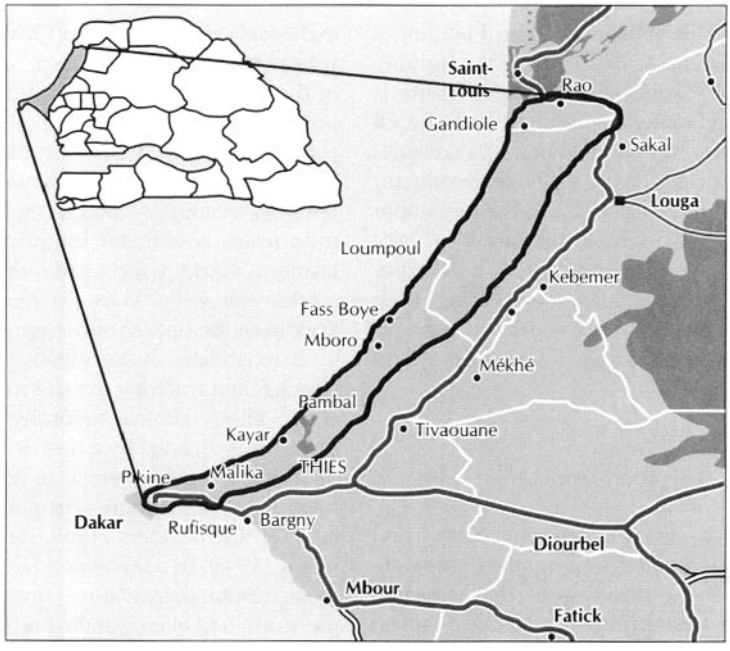

Fig. 10.1. The Niayes of Senegal.

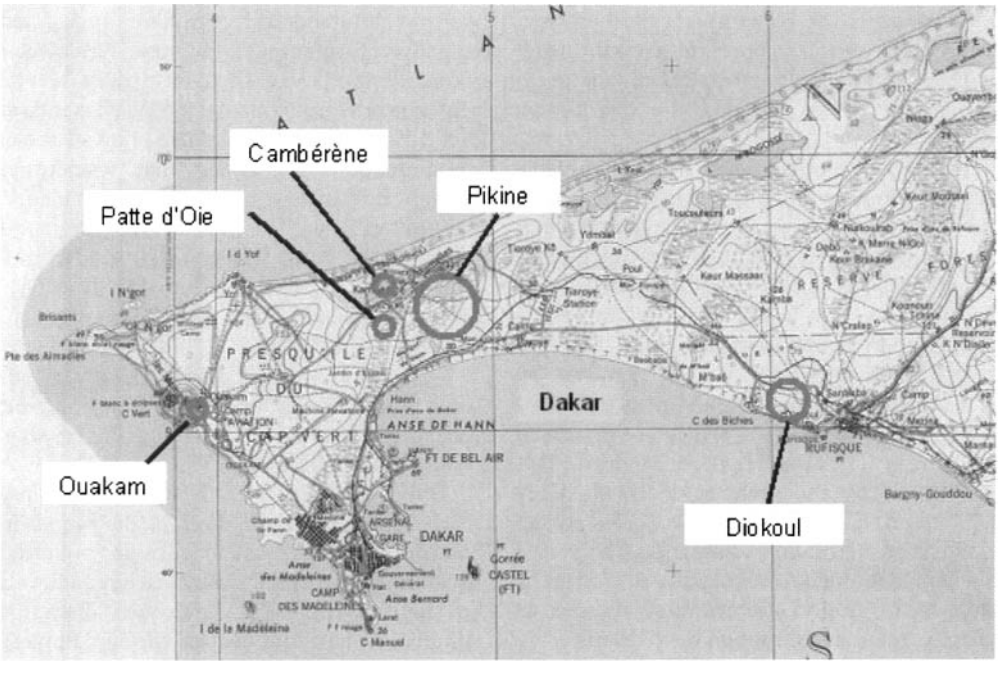

Fig. 10.2. Urban gardening in Dakar, enlarged from Fig.10.1.

Although Dakar has an Urban Plan and a 1964 Loi du Domaine National (LDN) [Republic of Senegal (National), 1964] land tenure is precarious, and many use land without title. Of the 380 farmers in Pikine, about 40% consider themselves owners with legal or customary title to the land, 6% lease it, and the remainder farm without any right to the land – a risky proposition. In 1999, municipal authorities expelled 50 farmers after discovering their plots near the airport. Also, without security of tenure, most farmers invest little in the land they cultivate.

Irrigation sources

Water supply, wastewater collection, and treatment are divided among three separate entities under the direction of the Ministère Hydraulique. Distribution has been privatised and devolved to Sénégalaise des Eaux (SDE). Operation and maintenance is controlled by Société National pour l'Exploitation des Eaux (SONES), while the Office Nationale de l'Assainissement (ONAS) operate sewerage services. SDE provides two main sources of water for Dakar – 20% comes from Lac de Guieres, where it is screened, clarified, and chlorinated, and 80% comes from groundwater at Thies, 80 km northeast of Dakar, where it is chlorinated before entering the distribution system.

A few farmers use water from the potable distribution network, but this is too expensive for most. The main sources of irrigation water are therefore *céanes* and untreated wastewater. *Céanes* are large, shallow hand-dug wells up to 3 m deep and 5 m in diameter, and are highly saline due to their close proximity to the coast. Untreated wastewater is often accessed by breaking into the mains that carry untreated wastewater, 180,000 m^3 of which are generated daily in Dakar. Of this, about 66,000 m^3, or 40%, is collected by the sewerage network. Only 4,000 m^3, or a mere 6% of the collected wastewater is treated before discharge. The rest is discharged through cesspools and unlined septic tanks to the ground and eventually the sea, or directly into the sea through open drains.

The irrigation source varies at each site, depending on access. At Cambérène, farmers exclusively use *céanes*, but at Ouakam, untreated wastewater is the only source. In Pikine, some of the farmers have access to both *céanes* and untreated wastewater, and the wastewater actually helps to access the *céane* water. The deeper the *céanes* are dug, the more saline they become, eventually becoming so saline that their water is unfit for irrigation. Thus, some farmers dilute water from the *céanes* with wastewater, which is less saline, by channeling flow from the broken sewerage mains.

In most cases, farmers wade directly into the *céanes*, filling watering cans for irrigation. Wastewater either drains naturally from broken pipes, or is directed by a hose into a depression or a *céane*, from where it is collected. Using these manual techniques, irrigation takes up to 60% of the farmers' time (Navez, cited in Niang, 1999). In a few cases, farmers use hoses to distribute wastewater – one rare farmer in the study had even installed an electric pump.

Analysis of the raw wastewater at each site showed expected results (Table 10.1) with some variance mainly due to the condition of the mains, i.e. how much storm water was in the system. Not surprisingly, the number of faecal coliform (FC), an indicator of pathogenic bacteria, far exceeded the 1000 FC/100 ml of water WHO standard required for unrestricted irrigation. Furthermore, the raw wastewater contained the larvae, eggs, or cysts of several protozoa or worms – above the WHO standard of 1/l. Some of the *céanes* also showed faecal contamination, suggesting that wastewater from the broken sewer mains is infiltrating into the groundwater. The most commonly found parasites are *Ascaris lumbricoides* (roundworm), *Entamœba coli* (which causes amoebic dysentery) and *Strongyloides stercolaris* (threadworm) (ENDA–IFAN, 2002).

Only trace amounts of most heavy metals were found, except for copper (Cu) and zinc, (Zn) which had levels only slightly higher than recommended (Rodier, 1996).

The characteristics of the wastewater vary markedly on separate days of the week. In Senegalese culture, certain days are preferred for laundry, and on these days, detergent levels are high. On Fridays, mosques discharge ablution water from *Jumma* (Friday Prayer), resulting in increased dilution and lower concentration levels for all parameters.

Table 10.1. Water quality[a] from various sources in parts of Dakar, Senegal.

Location	Water source	TSS (mg/l)	COD (mg/l)	K (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	P_2O_5 (mg/l)	FC (/100 ml)
Pikine	Deep well	28	300	132	14	0	1.49	N/A
	Shallow wells (*Céanes*)	438	282	100	37	4.5	80	17×10^3
	Raw wastewater	3,891	1,350	247.2	0.33	2.96	167	
Ouakam	Raw wastewater (rainy season)	1,299	367	65	0.4	1.02	57	47×10^4–47×10^5
	Raw wastewater (winter)	933	317	96	0.08	0.48	55	47×10^4–47×10^5
Patte d'Oie	Raw wastewater (rainy season)	7,491	1,606	136.8	0.54	0.72	147	N/A

[a] TSS = total suspended solids; COD = chemical oxygen demand; K = potassium; NO_3 = nitrate; NO_2 = nitrite; P_2O_5 = phosphate; FC = faecal coliform.

Crop productivity using wastewater

Depending on the growth period of their crops, farmers on average needed only 10 mm/day of wastewater for irrigation, compared to 12 mm/day for *céane* water (Gaye and Niang, 2002). Although the vigorous plant growth resulting from the nitrogen in wastewater would generally require even more water, this need is offset by the increase in soil organic matter that boosts its water-holding capacity.

The study found that, except for lettuce, most crops produced higher yields when watered with untreated wastewater without the addition of artificial fertilisers, than when farmers used piped potable water with added artificial fertilisers. For farmers using artificial fertilisers, these costs represent an average of 23% of their total farming costs (ENDA–IFAN, 2002). Possibly for this reason – higher yields from the same plot size – farmers who use raw wastewater have an average plot size of 0.02 ha, compared to 0.05 ha for those who use *céanes* water (ENDA–IFAN, 2002).

Table 10.2. Parasite prevalence at Ouakam and Pikine.

	Ouakam (raw wastewater) (%)	Pikine (*céanes* and raw wastewater) (%)
Prevalence	60	41
Type of parasites observed		
Ascaris	35	21
Entamoeba coli	28	35
Endolimax nana	25	0
Other	13	44

Moreover, the results also show that wastewater irrigation reduces the growth period for crops. For example, the typical period of maturity for lettuce is approximately 30 days, but drops to 20–25 days when using raw wastewater. Given that the usual growing season is November to April, this makes nine harvests possible instead of six – an increase of 50%. One drawback is that although wastewater-grown lettuce is larger, it is also less dense, yielding only 40 t/ha compared to 45 t/ha. Additionally, such lettuce spoils faster and must be sold within 24 hours of harvest (Faruqui, 2001). Similar results were found with aubergines.

About 75% of urban farmers farm year-round – the remainder work on their gardens 10 months of the year. However, 99% of farmers using wastewater practice their trade year-round. One reason for this is that wastewater-irrigated lettuce is more resistant to insects and the plant disease they cause – both of which are more prevalent during the wet season – and thus it can be grown successfully year-round. It is not yet known whether other crops exhibit this characteristic.

For all of the above reasons, the farmers interviewed have a definite preference for using raw wastewater, as it simply translates into higher annual profits. Those using wastewater reported earning very good profits during the dry season, when the price for lettuce is high due to limited supply. One farmer in Patte d'Oie said: "If I could have a permanent supply of raw wastewater for irrigation ... without being bothered by the health authorities, I could feed (support) more than 30 people."

Health and Environmental Effects

Health effects

Many farmers suffer from ill health because of their direct contact with wastewater – the lack of footwear or gloves makes them vulnerable to infection by parasites, transmitted either orally (placing unwashed hands in the mouth) or through the skin (parasites burrowing directly into the body).

At Ouakam, where only wastewater is available, 60% of farmers were infected with intestinal parasites. At Pikine, where water sources are mixed, the level of infection was lower – about 40%. The most common parasites found were *Ascaris ascaris* (roundworm), *Trichuris trichiura* (whipworm), and *Strongyloides stercoraltis* (threadworm). The eggs or larvae of all three worms, which live in the intestine, are passed through the faeces. In the case of roundworm and whipworm, reinfection is then oral, by ingesting food contaminated by the infective eggs. Threadworm, like hookworm infects by penetrating the skin of the feet or hands of farmers working in fields irrigated with wastewater.

A high density of *Plasmodium falciparum*, a parasite that causes malaria, was found in four farmers who irrigated *céanes* at Pikine. Malaria is endemic to the area, with many *Anopheles* mosquitoes present. Farmers using raw wastewater for irrigation were not infected, probably because raw wastewater is usually too dirty for mosquito larvae to thrive.

Sanitary quality of products

Recently harvested wastewater-irrigated plants for sale were found to be contaminated with amongst other pathogens, *Amoebae*, *Ancylostoma*, and *Ascaris* which cause amoebic dysentery, hookworm, and ascriasis (roundworm), respectively (Niang, 1999). Given that some of the farmers are also infected with whipworm (see above), eggs of this pathogen are also present in produce irrigated by wastewater. In the past, even more serious pathogens have been found on produce for sale in Dakar. The 1987 epidemic of typhoid caused by *Salmonella typhi* made 400 people in Dakar seriously ill. The disease originated from the consumption of vegetables contaminated with untreated wastewater, and mostly affected urban farmers who had used insufficiently treated wastewater for irrigation.

Almost half of the farmers indicated they were aware of the health risk posed by working with wastewater. However, only a handful used precautions such as wearing boots and gloves, or avoided direct contact. Furthermore, less than 15% were aware that the 1987 outbreak was caused by untreated wastewater use – in fact, many argued it was caused by other factors. Some of those unaware of the health risks are also under the impression that when water is clear, it must be clean.

For consumers, the main concern is over lettuce, onions, and tomatoes, which are most often eaten raw. Without close examination, it is impossible to tell the difference between products irrigated with water from different sources that are sold side by side. Rinsing is insufficient protection – health risks must be mitigated either by disinfecting, using a solution of sodium hypochlorite (bleach) or potassium permanganate, or by cooking. According to the ENDA–IFAN survey, a surprisingly high percentage of consumers (about 70%) are aware of health risks, and either disinfect or eat only cooked vegetables, although other surveys have found only 44% disinfect their vegetables (ENDA–IFAN, 2002). Of course, these solutions also carry risks if too high a concentration of disinfectant is used. Moreover, even using the higher figures of the more recent study, a significant minority of consumers (30%) are unaware of the risks, or take no protective measures.

For people living near the pilot wastewater treatment plants in Castor and Rufisque, an equal concern is the potentially negative health impacts from the treatment plants. To assuage

these concerns, the research team carried out epidemiological studies on people, including children, living near the sites. The results found no significant differences in their health from that of the general population. The main concern is diseases transmitted by mosquitoes, including malaria, yellow fever and elephantiasis. During the study period, mosquito species causing malaria (*Anopheles gambiae)* or yellow fever (*Aedes aegypti*) were not present in the ponds, although *Culex* mosquitoes, which transmit elephantiasis, were found. Mosquitoes tend to be associated with the last pond in the series of basins that make up the treatment system, where the water is cleaner. Possible solutions to reduce mosquitoes include placing fish to eat the larvae in the last basin, or adding an additional shallow pond with a gravel bed.

Environmental effects

Very little data exist on other environmental impacts of untreated wastewater irrigation, such as impact on soils or drinking water. Certainly, most of the shallow groundwater is contaminated with pathogens. However, this is because less than 40% of Dakar is connected to the sewerage network, and even the existing infrastructure is in disrepair. Wastewater is also unlikely to affect drinking water, since the *céanes* are too salty to serve as a drinking water source.

Somewhat surprisingly, the research team collected no data establishing reduced yields, and only minimal data on soil damage associated with a build-up of oil, grease and suspended solids arising from repeated, long-term wastewater irrigation. This is probably due to the nature of the sandy or peat soils, which have large interstices between their soil particles. Nevertheless, over time this could prove to be a problem – only 27% of farmers were aware that repeated wastewater irrigation can impede infiltration by blocking pores between soil particles, eventually modifying soil structure.

Given that the majority of the catchments showed very little industrial waste in wastewater, scarce evidence of heavy metals such as cadmium (Cd), mercury (Hg), chromium (Cr^{6+}), nickel (Ni), or manganese (Mn), and only moderate levels of Cu and Zn, there is no evidence yet of other serious associated long-term health or environmental effects. The one known exception is in Rufisque (the location of the IDRC-supported treatment systems), where discharges from the Marisel tannery have increased salinity in the wastewater to the point where it is unusable for irrigation. Levels of discharged Cr^{6+} may also be high, although this has yet to be detected.

Socio-economic Characteristics of Urban Farming

Socio-economic profiles of farmers

Almost 90% of the surveyed farmers are men, mostly under 45 years old, and the primary wage earners in their families. This is in contrast to other African cities where urban farmers are mostly women. However, Dakar female family members do help during the harvests and act as intermediaries, selling crops in the market.

Of the urban gardeners 58% are former farmers who migrated to Dakar from rural areas, and they farm because it is familiar and profitable. For 75%, it is their main occupation. All ethnic groups are represented and the practice is not restricted to the poorest groups.

The farming systems differ widely, showing wide variability in plot size, intensity, and profit, and depend on various factors, including access to water or wastewater, socio-economic level, proximity to markets, land tenure, soil quality, and whether or not farming is the principal occupation.

Urban farmers in Dakar are partially organised, as some are associated with or part of the Groupes d'intérêt economique (GIE). GIEs are community-based economic associations that work to develop small-scale enterprises. GIEs help collect funds to operate the sewerage system in Castor and Rufisque, and help organise some of the UA farmers in Pikine.

Benefits

Crops are largely intended for the market, but a significant amount is for home consumption. The researchers were challenged in trying to make estimates of the economic value of this production, because while the farmers inter-

viewed stated they earn reasonable profits, they were either unable or unwilling to give precise figures. Based on the average response (through oral surveys), the farmers earn net revenues (profit) of about FCFA 43,000 (US$73)[1] per harvest. Given that each farmer's plot is on average 0.05 ha, the profit per harvest is about US$1460/ha.

Using the four most common crops, the study found that on average farmers harvest five crops per year. The net average annual profit for each farmer is then FCFA 215,000 (US$365), or FCFA 589 (US$1)/day – equal to the international poverty line. While this figure may seem low, the profit generated may be less important if urban farmers become completely self-sufficient in vegetables. Considering that food purchases by the poor in the urban areas of developing countries can be as much as 80% of their income, this is a considerable improvement in family wealth (Egziabher *et al.*, 1994). Furthermore, if the farmers are among that quarter of the population already at the international poverty line, the profit earned essentially doubles their income. However, these figures probably underestimate their income. Some of the urban farmers indicated they earned profits of up to FCFA 300,000 (US$510) per harvest, or FCFA 1.5 million (US$2,552) annually, and it is likely that their annual net revenues are closer to this figure. In addition, it is unlikely that farming provides the sole contribution to household income, as some farmers may undertake other activities, and other family members may also be working.

In addition to direct income benefits from UA, there are also indirect economic spin-offs. Although not yet directly estimated, anecdotal evidence indicates that urban gardening generates a variety of other economic activities related to food production, marketing, and the sale cycle. This helps create demand in sectors that produce such goods as tools and seeds, and such service sectors as transport.

Costs

As with benefits, it was difficult to assess input costs due to the informal nature of urban gardening and the reticence of some farmers to respond to surveys. A preliminary estimate of cost per farmer per plot per harvest (both for those using raw wastewater and water from *céanes*) is:

- Soil preparation – FCFA 8,682 (US$15)
- Equipment – FCFA 10,300 (US$17)
- Fertiliser and pesticides – FCFA 4,021 (US$7)
- Seeds – FCFA 7,140 (US$12)

A total cost per farmer per plot per harvest is thus about FCFA 30,000 (US$51), or, using an average estimate of five harvests/year, US$255/year. As noted earlier, farmers who do not use wastewater pay up to 23% of their total input costs for pesticides and fertilisers. In this example, it would amount to about FCFA 9,200 (US$16) – or twice what farmers using wastewater pay for fertiliser.

Furthermore, labour, except for that involved with soil preparation, is not fully accounted for above. Working backwards from the profit figures presented earlier, the estimated average gross revenue based on farmer's responses may be in the order of US$255 (costs) + US$365 (net income), or US$620 annual gross income.

Institutional and Legal Framework

Notwithstanding problems of land tenure, the practice of UA is generally encouraged in Senegal. In 1984, the State began incorporating horticulture into national economic plans and development strategies, and this culminated in 1994 in the creation of the Department of Horticulture. Its aim is to support small-scale agriculture through credit programmes, training, and access to tools, fertilisers, and pesticides; but actual financial support has been negligible and the activity remains firmly in the informal sector. At the municipal level, seven mayors (including Pikine's) and city councillors from West Africa signed the *Dakar Declaration* in March 2002 (IDRC, 2002), which stated their explicit support of UA. Although the *Declaration* specifically noted the widespread practice of wastewater use and its health risks, the municipalities are not yet able to regulate UA,

[1] Based on 17 July 2003 exchange rate of US$1 = CFA Francs 587.76.

or to provide management options for mitigating risks.

While UA is theoretically encouraged, unrestricted wastewater use is not, and is banned by the National Health Act (1983) and the Environment Act (2001). The Health Act (Article L–41) stipulates that the 'deposit of waste, septic tanks discharge, garbage, sludge, faeces are prohibited on all lands where fruit and vegetables consumed fresh and cultivated and where edible parts come into contact with this waste'. Moreover, organic fertilisers like manure and compost can only be placed on crops up to one month prior to harvest. Previously, both national and municipal officials had attempted to enforce the law, but efforts proved futile and not much is done now. For example, at the behest of health officials, ONAS repaired pipes, but farmers simply broke them again.

However, there is evidence that both state and municipal authorities are willing to confront the reality of wastewater use. For instance, the Ministère Hydraulique's Projet Eau Long Terme (PLT) 5-year plan for 2002–2007 recognises the potential of wastewater use as an effective instrument for managing water demand. Notably, ONAS has also recognised its value, and is prepared to support decentralised wastewater use systems, so long as health risks are minimised. ONAS has envisioned creating 160 small-scale, community-operated wastewater treatment systems, and 60,000 on-site treatment systems in the country – with the caveat that it first needs to be convinced of the efficiency and sustainability of such systems. Similarly, the *Dakar Declaration* explicitly recognises both the benefits and risks of widespread wastewater use. All of these developments contribute to a policy climate from which viable approaches to protect farmers and the public health could emerge.

Constraints to Sustainable Urban Agriculture Production

Environmental and public health issues

Environmental effects may become a growing problem, but significant restrictions would also arise from a serious health crisis such as the 1987 typhoid epidemic – global public awareness of health impacts will spread faster and reach more people than in 1984, due to the advances in information and communication technologies made in the last 20 years. In effect, such an episode would quickly generate worldwide publicity through the Internet, and magnify local knowledge of the issue (witness the 2003 SARS outbreak) – making a backlash more likely to occur.

This blowback could result in a possible crackdown on producers by health inspectors, and a temporary repair of broken sewers by ONAS which could have devastating impacts on urban farmers and the urban poor.

Insecurity of land tenure

Short of a major health epidemic, a far greater obstacle to UA is insecurity of land tenure. Large, green, city spaces within developing countries are rare, and Dakar's situation is threatened by the development of a new golf course and private homes adjoining the site of Technopole, a business park already built on the aquifer recharge zone of the *Niayes*. Furthermore, another part of the *Niayes*, east of National Highway 1 and west of the Dalifort neighbourhood is being developed by two urban development agencies – Société Nationale des Habitats à Loyer Modéré (SNHLM) and Société Centrale d'Aménagement des Terrains Urbains (SCAT–URBAM).

As urban planning and programming of the city does not include UA, small-scale producers are aware their land may be expropriated at any time by the state for projects in the 'public interest', and thus do not invest heavily in their land. Although La Loi sur le Domaine National (LDN) suggests that 'la terre appartient en premier lieu à celui qui la cultive' (those that cultivate the land have first rights to it), economic interests sometimes override the law (ENDA–IFAN, 2002). Also, development sometimes provides low-income housing – an acute need in Dakar. This limits the possibilities for maintaining UA plots in the *Niayes*, and means planners face the challenge of moderating competing interests over the productive green areas of Dakar.

Recommendations

Dakar is now at a crossroads, as authorities search for feasible and effective ways to regulate existing irrigation practices and to reduce their harmful effects. The opportunity to implement guidelines from the World Health Organization (WHO) for the treatment and safe use of wastewater for agriculture (Mara and Cairncross, 1989) should now be explored together with other management options.

Treat wastewater

The main recommendation is to treat domestic wastewater to meet WHO guidelines for unrestricted use. Non-functioning treatment plants, abandoned due to a lack of capacity and funds, already exist at Pikine and Patte d'Oie. Parts of these plants could be reused in a simple, low-cost system. Furthermore, at Pikine there are large *mares* or ponds that could be used as reservoirs to allow pathogens to die off, thus rendering the wastewater suitable for unrestricted irrigation (Redwood and Faruqui, 2002).

Over the last 3 years, IFAN has been pilot testing two aquatic treatment systems: one using water lettuce (*Pistia stratiotes)* in Castor, and the other using bulrushes *(Typha* spp.) along with tilapia in Diokoul. Research progress has been slow due to external conditions, but results so far have been encouraging – the natural treatment plants are clearly more robust than mechanical systems. First built in 1994, they survived for 5 years without maintenance or harvesting of the aquatic plants, and they continue to operate, albeit at less than optimal efficiency. In contrast, a mechanical treatment plant would probably have experienced complete failure over such a long period.

Results are also promising in terms of both biochemical oxygen demand (BOD) and total suspended solids (TSS) removal, since heavy metal levels in the influent of both plants are safe. The main problem is pathogen levels, which pose the greatest threat to public health. In both Castor and Diokoul, faecal coliform levels in the effluent exceeds 1000 FC/100 ml, and intestinal pathogens are present, meaning the wastewater should not be used for unrestricted irrigation, although it could be used for restricted irrigation. This stems from inadequate residence time for pathogen die-off, and a second phase of the research project will focus on bringing the existing treatment systems in line with the WHO guidelines.These include a different orientation to increase hydraulic retention time. One important aspect of this study will be to map potential industrial contamination that may be preventing the re-growth of aquatic plants.

While initial results are encouraging, and capital and operations and maintenance costs to date have been low, this is no guarantee that the proposed treatment systems will be cost-effective and sustainable in achieving a water quality suitable for unrestricted irrigation. That possibility notwithstanding, it is still recommended that some level of treatment be provided to reduce health risks, and remove oil, grease, and suspended solids that could harm plants and ultimately modify soil structure. However, this does necessitate an investigation of other means to lower risks.

Other management options

The benefits and costs of the following proposed non-treatment management options will be studied in the next phase of the research project.

Increase public knowledge and awareness

Education programmes for farmers, the public, and municipal officials are essential complements to other risk-reduction tools. The findings in this paper could form the basis for awareness-raising strategies that focus on benefits, risks, and mitigation strategies, designed in line with WHO guidelines. In order to ensure that wastewater management is relevant and has a lasting effect, awareness strategies need to be comprehensive and broad-based, i.e. using such tools as schools and media campaigns, along with non-secular tools.

Culture, including religion, clearly influences how people perceive and manage a resource, and this is increasingly recognised by such

organisations as the United Nations Environment Programme (UNEP), the Food and Agriculture Organization of the United Nations (FAO) and the WHO, which have drawn on this connection for programmes in Afghanistan and Jordan. The degree to which people are influenced by religion varies among and within countries, but given that Senegal's population is predominately Muslim, there is an opportunity to use Islamic teachings to encourage safe irrigation practices. In Dakar, one of the main zones of wastewater use, Ouakam, is close to La Mosquée de la Divinité, and more than 40% of the children in the area attend Islamic school. As indicated in *Water Management in Islam* (Faruqui *et al.*, 2001), explicit support for water conservation is found in Islamic religious texts that place a great premium on cleanliness; wastewater use is allowable, but only when it has been treated sufficiently to protect public health.

Socio-cultural beliefs may also provide indirect opportunities, as farmers could be asked not to irrigate on laundry day (or the day after) because of the high levels of detergent in the water. Instead, they could try to irrigate on Fridays (after *Jumma*) when the water is more diluted following ablutions at the mosques. In Jordan, an IDRC-supported project on greywater use is reusing the *wudu* wastewater to irrigate olive trees in the mosque's courtyard. There is no reason why *wudu* water cannot be used from every single mosque in the world with a patch of land, including those in Dakar.

Use safer irrigation methods

Irrigation methods can affect both the degree of plant contamination and the types of precautions farmers can take to protect their own health. The current method of irrigating with watering cans intensifies the risk of contamination because droplets touch the plant leaves. The research project confirmed that lettuce watered this way is more contaminated by faecal coliforms and *Streptococcus* than lettuce irrigated by furrow (ENDA–IFAN, 2002). However, hose use depends on topography unless farmers install pumps. Where feasible, distribution lines could be fitted with drip irrigators so the wastewater wets the root zone directly without contacting the plant leaves. As an added benefit, this also reduces water consumption per unit area, but probably not in aggregate terms if the irrigated area expands.

In terms of implementation, micro-credit schemes exist in Dakar that could help make such basic tools as trickle irrigation systems, small pumps, and protective gear available to urban farmers. The Department of Horticulture could become more active in propagating these low-tech preventative methods. However, insecure land tenure means that farmers are reluctant to make greater investments in their enterprises, even though improved irrigation methods would improve their personal health.

The timing of wastewater use can also reduce impacts on health. WHO guidelines recommend that wastewater irrigation should be stopped 2 weeks before harvest (Mara and Cairncross, 1989). For those without an alternative water source, irrigation should be stopped at least 2 or 3 days before harvest, because this reduces pathogens on the leaves of produce. The use of setbacks (up to 300 feet) should also be considered for larger plots within urban areas (OAS, 1997).

To protect farmers, health authorities could make wearing boots and gloves when irrigating mandatory – the problem however is that farmers do not like wearing gloves in hot weather, and most *céanes* are deeper than boot length. Under the current passive method of collection and distribution, i.e. allowing wastewater to drain into the *céanes* and watering with cans, wearing gloves and boots is unlikely to be feasible, although even now, farmers could at least wear shoes when walking in their fields. As an alternative, wastewater could be pumped up to raised treatment and storage tanks, from where it could flow into the fields via hoses or furrows or be collected in watering cans from standpipes. However, until the feasibility of decentralised treatment is proven, this approach will be limited to the IDRC pilot test during the next phase of research. This example however, illustrates the point that treatment options and other management options are not mutually exclusive – in fact they depend on each other.

Crop restrictions

Given that many of the crops watered with wastewater are some of the most profitable, it may be difficult to enforce crop restrictions. Nevertheless, until viable treatment systems are in place, this practice should be discouraged, even if focusing on vegetables, such as aubergine that are eaten cooked, lowers profits. However crop restrictions alone have proven impractical in other jurisdictions, so such measures must be combined with a methodical public awareness and farmer education programme. Additionally where regulation fails, markets may succeed, as there may be reduced consumer demand to purchase wastewater-irrigated raw vegetables, if consumers realise the hazards.

Improve institutional coordination

The current research has identified a lack of collaboration between such non-governmental institutions as the farmers themselves, groups representing them, e.g. Groupes d'Intérêt Economique (GIE), and governmental organisations such as municipalities (the Commune of Dakar), and national departments such as the Ministries of Agriculture, Health, Urban Planning, and SONES. An important part of the next phase of the project will be regular meetings bringing all stakeholders together to brainstorm for mutually satisfactory solutions.

Treat infections

Another potential solution is medical treatment for farmers to assuage chronic health problems such as bacterial and worm infections (RUAF, 2002). Granted, such an approach is reactive rather than preventive, but until other solutions are better advanced, it may be the only way to protect farmers' health. The benefits and costs of this approach will also be assessed during the next phase of IDRC research.

Conduct research

The informal and quasi-illegal nature of UA activity, and the cost and time required to do methodical research, means many findings only probe the surface. Although they provide qualitative data or trend directions, they do not fully answer questions, and indeed, raise new ones. Because of this, some of the above recommendations are tentative. As already noted, key research gaps must be addressed by meaningful research before such recommendations can be significantly implemented. These gaps include:

- Designing efficient and sustainable natural wastewater treatment systems
- Finding the best institutional policies and framework to help municipal and national institutions work together in support of urban farmers and to protect public health
- Testing the feasibility of non-treatment management options.

In addition, in order to attract increased donor and state funding (see below), the following information is required:

- Better economic estimates of the value of UA to emphasise its importance for poverty alleviation to donors and policy-makers
- More accurate estimates of the economic value-addition of wastewater use in urban agriculture.

Increased donor/state funding

Finally, donor and state funding is essential to help policy-makers strike a balance between protecting the public interest, the farmers, and the urban poor. ONAS in partnership with UN Habitat and the World Bank suggest that decentralised treatment and use is a serious option for wastewater management in Senegal. However, without additional funding, neither the treatment, nor other management options can be implemented. A real opportunity exists to seriously mitigate risks, provided funds are forthcoming.

Conclusions

Farmers prefer using wastewater to freshwater for irrigation, as they immediately see higher profits. However, few take precautions to protect themselves, and as a result, 60% of them are plagued with intestinal parasites. Additionally, the practice poses a significant public health risk, as three of the main crops are most often eaten raw. Urban agriculture itself is

constrained by the insecurity of land tenure, as the constant threat of losing their land makes farmers unwilling to commit to major investments. Thus the potential for safer and more convenient irrigation methods, such as hoses fitted with drip irrigators, is limited.

While policy-makers have largely ignored UA in the past, they are increasingly encouraging its practice, while simultaneously attempting to discourage its dangerous use of raw wastewater. Policy-makers such as ONAS are emphasising treatment and are prepared to decentralise wastewater treatment to the community level, so long as efficient and sustainable systems can be identified. It is recommended that action research be conducted that balances both private and public needs, including testing for effective treatment systems. At the same time, the feasibility of such other management options as increasing public awareness, using safer irrigation methods, and practising restricted irrigation should also be explored. These treatment and non-treatment options are complementary, and unless action is taken soon, a repeat of the 1987 typhoid epidemic could lead to a backlash among consumers and policy-makers, with devastating consequences for both poor farmers and poor consumers.

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11 Wastewater Irrigation in Vadodara, Gujarat, India: Economic Catalyst for Marginalised Communities

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Abstract

Wastewater is gaining popularity as a source of irrigation water in different countries around the world. This is especially true in India, where it has been in use for a long time. Its economic benefits and its importance as a coping strategy for the poor have had little recognition. The rural areas downstream of Vadodara in Gujarat, India, present an interesting case where wastewater supports annual agricultural production worth Rs. 266 million (US$5.5 million). Both food crops and cash crops are irrigated by domestic wastewater and industrial effluent. In this area one of the most lucrative income-generating activities for the lower social strata is the sale of wastewater (and renting pumps to lift it). The lack of alternative sources of water has generated viable markets for wastewater. Increased disposable incomes have resulted from the catalytic use of wastewater that was formerly not socially acceptable, i.e. the farmers considered it unhealthy and unclean. The use of wastewater to grow food crops poses uncertain risks to the health of both consumers and those who actually handle the wastewater. Livestock, land and groundwater resources are also at risk. City planners and administrators view wastewater as a disposal problem. They are not concerned with the impact on the livelihoods it presently generates or with the health of the stakeholders. Politics and corruption play an important role in the decision to construct expensive treatment plants that often fail to function properly, if at all, once they are commissioned. The dynamics of agricultural wastewater use and a potential roadmap for optimal productivity are presented in this chapter.

Background

Worldwide the role of wastewater in agriculture has become increasingly important. Its agricultural use is not limited to arid areas. Humid regions like Vietnam (Raschid-Sally *et al.*, Chapter 7, this volume) also make efficient use of wastewater. As both industry and populations continue to increase and freshwater availability decreases, wastewater becomes an important regional planning variable.

In India, wastewater irrigation is increasingly used for such crops as vegetables, fruits, cereals, flowers and fodder. Kolkata (formerly Calcutta) has a long history of using wastewater stabilisation tanks for aquaculture. An estimated 2.4 t/ha (Gopal *et al.*, 1991) of fish is produced annually in Kolkata from about 3200 ha of ponds with inflow of about 3 m^3/sec Throughout India industries recycle wastewater to reduce the requirements for freshwater. This trend is led by industries in

 Wastewater Use in Irrigated Agriculture
(eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

Saurashtra, Gujarat and Chennai, Tamil Nadu. Vadodara is the third largest city in Gujarat and growing rapidly. At present, water there is used by three major sectors. Industrial use began in the 1950s and 1960s with oil, chemical and pharmaceutical plants. It is concentrated in such peri-urban areas as Nandesari, Bajuva, Ranoli and Makarpura, where a separate effluent channel handles much of the industrial effluent. Domestic water supply serves a population estimated at about 1.5 million in 2001. A large agricultural area extends well beyond the peri-urban limits into the rural areas to the southwest of the city. Municipal sewage is used to grow vegetables, wheat, paddy rice, and flowers along an 80-km stretch of the rivers Jambuva, Vishwamitri and Dhadar [termed the municipal sewage use area (MSU area), in this chapter]. Effluent is also used for irrigation along a 56.3-km stretch of the Effluent Channel Project (termed the ECP area).

Annual rainfall in the region averages approximately 800 mm, but, there was a 3-year drought in 1999–2002. Flat land that slopes gently towards the sea characterises the topography. Due to proximity to the sea, saline water ingress is a problem that limits the availability, discharge, and duration of operation of wells for exploiting groundwater. The region is classified as a 'No-Source Zone' by the State Ground Water Board, signifying that there are no new freshwater sources that could be tapped. The very high degree of urbanisation assures farmers of stable and lucrative markets.

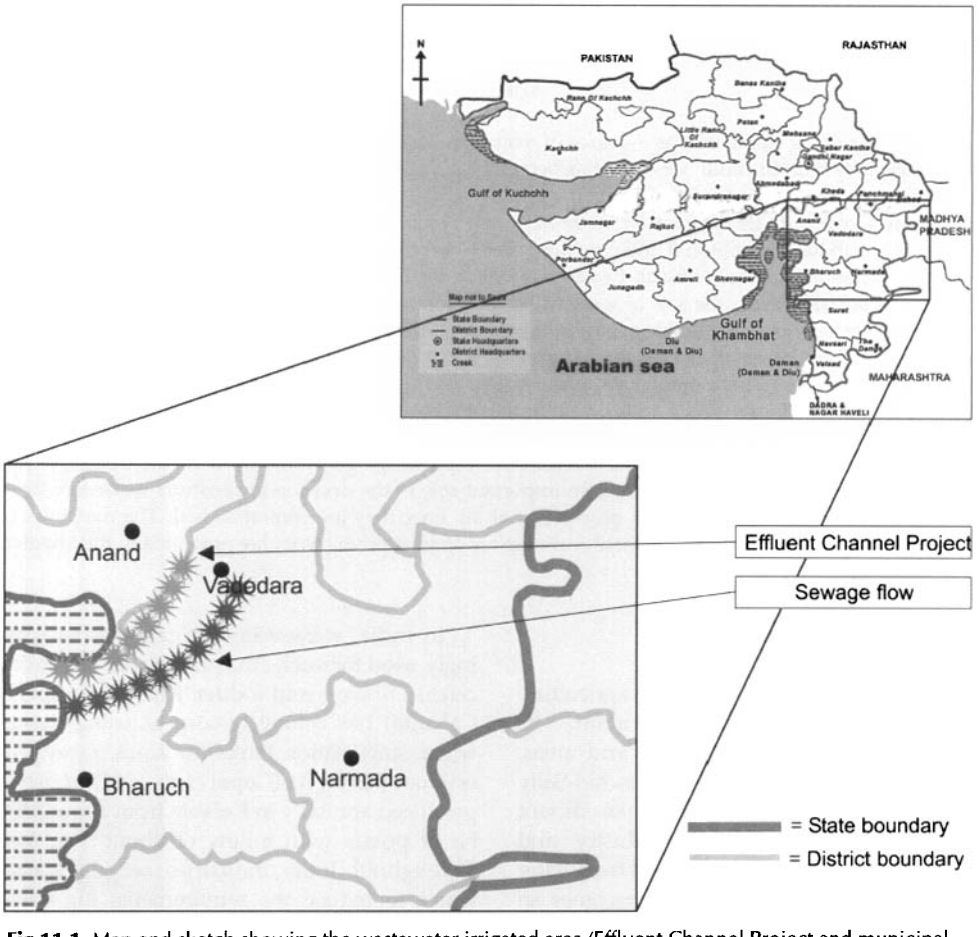

Fig 11.1. Map and sketch showing the wastewater irrigated area (Effluent Channel Project and municipal sewage use areas) around Vadodara, Gujarat, India.

The ECP is a concrete-lined covered channel 56.3-km long. It disposes 18 million gallons/day (MGD) of treated effluent into the Cambay Channel leading to the Gulf of Cambay. The ECP follows guidelines and procedures developed by the National Environmental and Engineering Research Institute (NEERI) at Nagpur. Nine industries joined together to plan, promote and execute the project that was commissioned in 1983 at a cost of Rs.130 million (approximately US$14 million in 1983). Wheat, tobacco and pearl millet production characterise the agriculture in the region. Untreated effluents are illegally and flagrantly released by erring industries into the last few kilometres of the channel, and cause widespread land degradation and crop loss.

In 1962, the city was divided into three drainage zones, each equipped with a collection system and a sewage treatment plant (STP). The effluent from the treatment plants discharges into the Ruparel Kaans, then into the natural seasonal river system of the Vishwamitri to the southwest of the city, and finally joins the Dhadar River and runs into the sea.

At present none of the three STPs is fully functional. The oldest, Gajrawadi STP, is now beyond repair. It receives close to 85 million litres per day (MLD) of sewage. At the Atladra STP, only the primary settling tank is in working condition, and only partially treats 27 MLD. The Tarsali STP utilises obsolete oxidation ditch technology. Although it receives 40 MLD of sewage, according to a report submitted to Vadodara Municipal Corporation for the future planning of a sewage collection system (AIC Watson Consultants Ltd, 1999), it only has a capacity of 9 MLD. In the village of Kapurai, farmers buy municipal sewage from the municipality to use for irrigation.

Methodology

The methodology for the study comprised a combination of the following:

- Exploratory visits to the area that were necessary to comprehend the region and the issues involved.
- Preliminary group discussions that were helpful in sample design and planning, for the selection of study tools and for qualitative analysis.
- The sample design which involved selecting five villages along the ECP area and 10 along the MSU area. Villages were chosen from along each bank, maintaining a uniform spread over the whole area. For the MSU area this sample comprised eight villages along the river Dhadar, and one village each along the rivers Vishwamitri and Jambuva (where the flow length is short). In the ECP area, the area was divided into six sample sites depending on the intensity and cropping pattern of agriculture. A village was chosen from the centre of each of five sites. The sixth site was excluded, as the Effluent Channel Project Limited (ECPL) authorities permit little or no use of effluent for irrigation there.

Through group discussions the extent, type and interlinkages involved in the use of wastewater for irrigation were estimated.

Three questionnaire surveys were carried out at the farmer and household levels. One questionnaire dealt with agriculture-related information and included a minimum of eight farmers from each group using wastewater, groundwater and rainfed agriculture, totalling 25 in each village. The second questionnaire pertained to the health impacts of water use and covered 25 households from each village including a significant number of households that use wastewater. The third questionnaire captured the dynamics of water markets for irrigation and was administered to three wastewater and two freshwater sellers in each village. The questionnaires consisted of structured closed-ended and open-ended questions supported by informal discussions with respondents and non-respondents alike.

Data on crop economics were collected at the village level and aggregated by crop for the study area. This was done to reduce the error due to direct extrapolation from field to study area level. The statistical package for social sciences (SPSS) and Excel were used to determine the averages, variations and correlations. The results were confirmed through the focus

group discussions with the farmers and interviews with the farmers in the villages.

Results and Discussions

Municipal sewage use (MSU) area

About 200 years ago the Dhadar was a perennial river but over time became seasonal, carrying water only during the monsoon. Municipal sewage started flowing in 1962 when the three STPs were commissioned. Since then the perennial flow in the Dhadar has been restored, albeit with municipal sewage. Only twice in its 41 years of wastewater conveyance has the river dried up (70 km downstream of Vadodara city beyond Amod) (Bhamoriya, 2002). The characteristics of water use including wastewater, groundwater and rainfed farming in the MSU area are presented in Table 11.1.

Group discussions elicited the fact that rainfed farmers marginalised by failing rains were an important group that had converted to wastewater irrigation. Wastewater farmers have been using municipal sewage for about 7–8 years on average. Because wastewater is available, farmers have been able to bring a significant area of land under cultivation and irrigation. Wastewater agriculture has thus become an attractive livelihood option in the area.

Three cropping seasons are possible. The most common crops grown with wastewater irrigation are:

- Rainy season (*kharif*): Pearl millet, tobacco, rice and elephant grass
- Postrainy season (*rabi*): Wheat, tobacco, banana and elephant grass
- Summer: Pearl millet and elephant grass.

ECP area

The effluent channel conveys treated industrial effluent for 56 km before discharging into the sea. The extent of the wastewater-irrigated area along the channel is less than that of the MSU area. There is intensive agricultural use of effluent close to the channel itself, but there is systematic under-reporting on its prevalence, because it is illegal to lift effluent to irrigate fields.

Prior to using wastewater, farmers had no source of irrigation water. About 8–9 years ago they discovered the benefits of wastewater irrigation (although some farmers claim to have been using it since 1983). They would prefer to use freshwater but this is not an option here. The recent drought years have seen an increase in the use of effluent for a variety of other purposes, like drinking water for cattle, and for washing utensils and clothes, thus exposing the population to undocumented health hazards.

The farmers reported pH variations in the effluent ranging from 2 to 11, which can be very detrimental to crops, so they steal pH-measuring strips from nearby factories to check the pH of the effluent, and only use it when the pH is between 6.5 and 8.5.

Downstream of Uber untreated wastes brought in by trucks from as far away as Jagadhia and Bharuch are discharged into the

Table 11.1. Comparison of wastewater and groundwater (tubewell-irrigated) and rainfed agriculture in the MSU area.

	Wastewater	Tubewell	Rainfed
Family size (number)	4.9	4.4	4.6
Total landholding (ha)	3.5	3.4	2.6
Off-farm wage earning members (number)	1.7	1.3	1.6
Income from off-farm sources (Rs./month)	1756	1513	1890
(US$/month)	(36.58)	(31.52)	(39.38)
Years since first use of wastewater	8.3	~0	0.1
Distance from source of irrigation (m)	160	175	–

Table 11.2. Comparison of wastewater and tubewell-irrigated and rainfed agriculture along the Effluent Channel Project (ECP).

	Wastewater	Tubewell	Rainfed
Family size (number)	4.98	4.54	4.95
Total landholding (ha)	2.7	3.1	2.4
Other earning family members (number)	1.4	1.3	1.8
Income from other sources (Rs./month)	1,835	1,927	1,715
(US$/month)	(38.23)	(40.15)	(35.73)
Years since first use of wastewater	8.6	0.7	0.4
Distance from source of irrigation (m)	90	75	230[a]

[a] Some critical protective irrigation can be given by a few to their *kharif* crop when the rains fail, hence this value appears.

ECP channel. From this point downstream, the effluent flow is totally unfit for agriculture. Even upstream along the ECP channel, many farmers who took up wastewater irrigation now find that their land has become infertile or they have incurred heavy crop losses, and as a result have been forced to leave agriculture.

Coping with Poverty: Creating A New Social Order

From information collected mainly through the focus group discussions supported by survey data it became clear that the region has suffered from unemployment as a direct result of water shortage in an area with a large population dependent on agriculture. The following social order existed before wastewater was used for irrigation, in order of incomes and economic opportunities:

Tubewell owners
Tubewell water buyers
Well owners
Employees of a factory or other unit
Shopkeeper/Trader in village
Rainfed farmer
Agricultural labourer

The top three groups represented irrigating farmers but well owners had limited available water and were dependent on rainfall to recharge their wells. As education and skill levels were low, employment was not very remunerative. Shopkeepers had limited markets within the villages. Rainfed farmers and agricultural labourers lived with the high risks and vulnerability of uncertainties linked to water availability for agriculture. A combination of accelerated pumping and erratic rainfall resulted in wells drying up and increasing groundwater salinity. The rural economy was unable to keep up with the larger processes of economic growth fuelled by industry and urbanisation.

In this crisis, some rainfed farmers rented pumps and applied wastewater to their fields to save their parched crops. This proved a revolutionary step. The stigma attached to wastewater use proved a barrier for the so-called 'well-to-do' to take up sewage as an irrigation option. This resulted in sewage use being self-selecting towards the poorer and marginalised sections of the society who had no options but to use it or face drought and poverty.

Sewage and industrial effluent flows have hardly any seasonality in quantity, and therefore are reliable and assured sources of irrigation. Farmers clearly indicate that wastewater is an excellent resource for poverty alleviation.

Besides the direct benefits to farmers who irrigate with wastewater, an indirect benefit has been the sale of wastewater. The data for water selling in Table 11.3 shows higher incomes (despite under reporting) for wastewater sellers (diesel pump owners) than for tubewell owners. This is partly based on the fact that the average pumping time for wastewater (11.25 hours/day) is twice that for groundwater tubewells (6.6 hours/day).

The increased income for wastewater sellers is because there are more customers and larger areas irrigated per diesel pump lifting

Table 11.3. Gross and net monthly incomes [Rs.(US$)] of different groups of water sellers.

	ECP area		MSU area	
	Gross monthly income	Net monthly income	Gross monthly income	Net monthly income
Tubewell water sellers	5,850 (121.88)	2,688 (56.00)	8,050 (167.71)	3,685 (76.77)
Pump-renting agents selling wastewater	10,642 (221.71)	3,467 (72.23)	10,810 (225.21)	4,167 (86.81)

Note: Rs.48 = US$1.

wastewater than those using groundwater from deep tubewells. This is despite the fact that diesel pumps cost more to run than electric pumps.

Wastewater has catapulted wastewater irrigators into the higher economic strata of irrigating farmers and pump owners (water sellers), which are the most remunerative agricultural occupations in the region. This process has benefited the poor and has helped to reduce social inequality.

In the ECP area there have been some interesting cropping shifts. Sugarcane that was not grown prior to the availability of effluent has been introduced. All the sugarcane farmers interviewed were irrigating their crops with effluent. The tubewell owners (groundwater irrigators) do not plant sugarcane because they do not have enough water. A similar trend is cultivation of banana, another remunerative cash crop. Amla (*Phyllanthus emblica*) (fruit) and drumstick (*Moringa oleifera*) trees whose edible seed pods are used as a vegetable are gaining popularity among wastewater irrigators as they provide a good source of revenue with less irrigation than sugarcane, thereby saving the cost of diesel needed to pump wastewater.

Agricultural Value and Impacts

Table 11.4 presents the cropped area derived from the field studies and calculates the value of agricultural production sustained by wastewater (both municipal and effluent).

Note that ECP and the MSU areas were estimated by extrapolating from irrigated area data collected at the village level (through focus group discussions) based on the total number and area of villages along the channel reaches known to receive wastewater. The average irrigation depth applied was calculated by dividing the total estimated wastewater irrigation volume by the gross cropped area.

Despite using only one-third of the municipal area and higher cropping intensity the value of produce from the ECP area is lower than that

Table 11.4. Estimated value of wastewater irrigation, Vadodara, Gujarat.

	ECP area	MSU area
Net cropped area (km^2)	14.8	39.7
Gross cropped area (km^2)	40.7	96.8
Cropping intensity	2.75	2.44
Total annual irrigation applied (cm)	292	198
Average irrigation depth applied (cm/crop)	106	81
Value of annual agricultural production (Rs.)	23,612,000	242,214,000
Total value	Rs.265,826,000 (US$5,538,000)	

from MSU area, because farmers under report fearing legal action against them for using effluent. The above calculations show that from 100 villages in the area the value of annual agricultural production is Rs.266 million (US$5.5 million).

In the MSU area there is no correlation between the horsepower of the pumps used and the area they irrigate, indicating that the irrigation depth applied is variable. However, there is a correlation between the horsepower of a given pump and the number of customers served, suggesting that higher discharge pumps are used in areas with small land-holdings. On the wastewater-irrigated farms fertiliser use has gone down, but pesticide use and labour inputs have increased in the past few years. The farmers recognise the fertiliser-saving benefit of wastewater and also the need for more pesticides because municipal sewage also contains plant pathogens.

Observations and Recommmendations

Agricultural production of net annual value Rs.266 million (US$5.5 million) is generated by wastewater irrigation in and around Vadodara. This substantial sum accrues to 100 villages – an annual average of Rs.2.66 million per village. Wastewater is now being used in an unregulated and sub-optimal manner. The health risks to humans and livestock exposed to sewage and industrial effluent are poorly understood, but undoubtedly have significant economic implications. There is a trade-off between sustaining the economic agricultural activity of 100 villages that have few other options than to irrigate with wastewater and the risks related to its use.

Wastewater is not viewed as a resource by civic authorities. City planners and administrators see it as a disposal problem, with no concern for the livelihoods it presently generates and little recognition of the health risks of stakeholders who use it. Planners and administrators need to identify wastewater as a critical input for agriculture and integrate this into wastewater management and disposal planning. Based on the very real threats to the consumers of wastewater-irrigated food products and to farmers directly and indirectly exposed to it, a research and management agenda must be developed in order to optimise wastewater use and balance its social costs and benefits.

The uncertainty associated with water availability for agriculture, particularly for marginalised farmers without access to groundwater, could be overcome to some extent with planned use of wastewater. Whilst wastewater irrigation represents the only agricultural production option for many farmers, there is increasing awareness of the benefits it brings if optimally used, particularly the opportunities it provides for marginalised groups. In order to achieve greater social gains, there is a need to improve users' knowledge of trade-offs and risk-mitigation strategies.

The present quantity of wastewater flows applied to agricultural land in Vadodara is sufficient to give 81 cm irrigation to each crop in the MSU areas, and 106 cm to each crop in the ECP areas. This signifies grossly inefficient use of wastewater for irrigation given that wheat, a prevalent winter crop in the region, needs only 49 cm of irrigation.

A planned initiative is needed to maximise the benefits that could be derived from wastewater resources. It will be necessary to develop knowledge-based agriculture, focusing on farming and irrigation practices suited to wastewater use systems to generate the maximum benefits.

A number of farmers are increasingly using wastewater conjunctively with other sources of water as a coping mechanism against water quality and scarcity problems. This group of farmers represents a potential 'regular user' group in that many of the current regular users started off using mixed water sources. The increasing number of users requires that the agricultural and planning authorities address the issue of wastewater agriculture on an urgent basis.

The ECPL faces the problem of not having enough funds to carry out even routine monitoring functions properly, as evidenced by the alarming pH variations of 2 to 11. They have to manage with composite samples rather than point samples which can help single out defaulters in treatment standards. The Pollution Control Board needs to develop ways to support the ECPL.

Sale of wastewater by pump owners who rent out their equipment is an indirect benefit of wastewater agriculture in the region. Particularly because of the low lift and associated energy costs, renting out pumps to lift wastewater is more remunerative than selling groundwater. The further development of wastewater markets could have far-reaching impacts on the use and development of this resource as a vehicle for economic prosperity. It might be feasible for the municipality to levy a fee on pump owners and a sewage discharge fee (sewerage cess) that could be used for pollution abatement and management, particularly through wastewater treatment and improved irrigation practices.

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12 The Use of Wastewater in Cochabamba, Bolivia: A Degrading Environment

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Abstract

In Cochabamba, Bolivia, wastewater is extensively used in urban and peri-urban agriculture. Both vegetable and fodder crops are irrigated with polluted water, i.e. diluted or partly treated municipal and industrial sewage containing high concentrations of pathogens, heavy metals and salts. Specifically in the downstream La Mayca area, where the farmers have an agreement with the municipal water and sewerage company, soil degradation has forced farmers to increasingly replace vegetable crops with more salt-tolerant fodder crops. In other areas around the city, cultivators deny using readily available wastewater, pointing to nearby wells as their water source. However, many wells are probably also polluted and do not yield enough water for the irrigated area served. Farmers state they are not confronted with specific health problems related to the use of polluted water, contradicting reports from local health workers. Low surface water flows and low rainfall, along with high (industrial) pollution and low wastewater treatment capacity mean that most of the water available to the farmers is of poor quality. Reduction of (industrial) pollution, increased treatment capacity and an integrated water management (IWM) approach, in which nearby good-quality groundwater could be used as a water source for blending with wastewater, represent options for improvement. However, strong traditional water rights, lack of urban planning, and weak institutions are constraints to the improvement of wastewater management in Cochabamba.

Introduction

In urban areas of many (developing) countries, urban and peri-urban agriculture depends, at least to some extent, on wastewater as a source of irrigation water. The quality of the water and the conditions under which this water is used vary greatly. In poor countries this water may, in extreme cases, take the form of diluted raw sewage, even if this is considered illegal.

 Wastewater Use in Irrigated Agriculture (eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

Lack of infrastructure results in uncontrolled wastewater flow. Legislation on wastewater discharge and use is either poorly developed or not enforced. Partial treatment at secondary level, typical of overloaded treatment plants, and natural treatment before agricultural use are more common. In general, irrigation with effluent that has been treated up to secondary level can be considered a cost-effective and environmentally safe way of handling domestic wastewater.

In countries where legislation and control are strict and where the economic conditions allow, industrial wastewater is separated from domestic wastewater. Domestic wastewater may receive secondary and sometimes tertiary treatment before it is made available for crop production. Even then, legislation can restrict the type of crops that are allowed to be grown and the irrigation technology to be used. For vegetable crops that are consumed raw, the most stringent conditions are applied.

Bolivia is a typical example of a country where, due to poverty and lack of planning and management capacity, uncontrolled use of wastewater takes place. Cochabamba, the regional capital of the agricultural centre of the country, is a typical example of untreated wastewater irrigation resulting from a shortage of freshwater resources, high levels of pollution from industrial and domestic origin, and insufficient water treatment capacity.

Bolivia

Bolivia, a land-locked country in Latin America, can be divided into three ecological regions. The western part of the country (the Altiplano) is 3,800 m above sea level, cold and relatively dry (300–600 mm annual rainfall). The capital La Paz (almost 1.6 million inhabitants) is situated in a valley of the Altiplano. The sub-Andean region, with Cochabamba (855,000 population) as a major departmental capital, is situated between the Altiplano and the eastern lowlands. Here, average temperatures are between 15° and 18°C and annual rainfall from 380–700 mm. The eastern lowlands (the Llanos) cover about 57% of Bolivia's total area. Their average temperature is high at 23°C and annual rainfall between 1,100–1,900 mm. The biggest city here is fast-growing Santa Cruz (1.5 million).

In the major cities, the urban population has increased by a yearly average of 3–6% in the last 50 years and is estimated now at 62% of the total population of 8.3 million compared to 42% in 1976. For Cochabamba the urbanisation rate rose from 38% in 1976 to 59% in 2001 (Durán *et al.*, 2003).

La Paz discharges all its wastewater, without any treatment, into the Choqueyapu river that runs through the city. Water from this river is used downstream for agriculture, including vegetable production.

Cochabamba is situated in the valleys between the Altiplano and the lowlands. Irrigated agriculture is focused on the production of fodder crops, including fodder maize and alfalfa, although many other crops, including vegetables, are grown for farmers' own consumption. The city has one central wastewater treatment plant (WWTP) with a capacity of 400 l/s. Its effluent, that is of low quality due to overloading of the plant, is used for irrigation. In housing areas there are a large number of septic tanks and Imhoff tanks for primary treatment. However, few of them are functioning properly.

Santa Cruz, the second largest city of Bolivia after La Paz, has three WWTPs with a total design capacity of about 380 l/s, which is low given the population. The WWTP discharge is not used for irrigation, as the immediate surroundings receive sufficient rainfall to meet farmers' needs.

In some other cities in Bolivia, the wastewater is of extremely poor quality, due to industrial activities. Such wastewater is discharged, without any treatment, into evaporation ponds, without any form of subsequent use.

Sewerage coverage is limited in Bolivia, particularly in comparison to other Latin American countries (World Bank, 1999). Yet, from Table 12.1 it can be seen that these coverage figures have increased enormously in the last 25 years, even more impressive if population growth in this same period is considered.

Table 12.1. Increase in access to water supply and sanitation in urban and rural Bolivia, 1976–97 (World Bank 1999).

		Coverage (%)		
		1976	1992	1997
Urban	Water supply	74	81	93
	Sanitation[a]	47	63	79
Rural	Water supply	9	24	37
	Sanitation[a]	4	17	33
Total	Water supply	39	58	72
	Sanitation[a]	22	43	61

[a] Data on sanitation facilities include domestic connections to a sewerage network, latrines and septic tanks.

Actual Use of Wastewater in Bolivia

Wastewater use can be defined as direct or indirect and be characterised as formal or informal:

- In the case of **direct use,** untreated discharge from the sewer or effluent from the treatment plant is directed to the crops. This includes discharge released by intentional ruptures of the sewer pipelines by farmers. The wastewater, treated or untreated, is not diluted before being used. This is a common phenomenon in the areas where water is scarce, e.g. Cochabamba.
- **Indirect use** refers to the use of surface water that is polluted with wastewater, raw or partly treated. In this case the wastewater is diluted before use, certainly in the wet season. In Bolivia, indirect use of wastewater takes place in almost all rural and peri-urban areas downstream of the urban centres.
- In the case of **formal use** a convention or other type of agreement supports the use of (treated) wastewater. There is only one such case known in Bolivia. In Cochabamba, the irrigator's organisation has an agreement with the municipal water and sewerage company (SEMAPA) for the use of their effluent.
- **Informal use** is not supported by any agreement. This is the case in most parts of Bolivia.

Table 12.2 gives an overview of the characteristics of wastewater use in Bolivia's main cities. Most wastewater use is indirect and informal, and is limited to the arid and semi-arid regions: the Altiplano and the Valleys. In the case of the Llanos region, where the rainfall is high, crops do not require irrigation and the wastewater is simply discharged into the rivers that are an important source of fish for indigenous people living downstream in the forests.

When wastewater in Bolivia is used directly the irrigators have at least some insight or

Table 12.2. Characteristics of wastewater use in peri-urban areas of the main cities in Bolivia (Durán *et al.*, 2003).

Departmental capital	Population ('000) (2001)	Characteristics of wastewater use
Cochabamba	855	Direct use of the effluent of the WWTP. Indirect use of polluted water from the Rocha river
La Paz El Alto	1,550	Indirect use from the Choqueyapu river, into which untreated wastewater is discharged. Indirect use through the Seco river where the effluent of the Puchuckollo WWTP is discharged
Santa Cruz	1,543	No wastewater use, high rainfall zone
Oruro	237	No wastewater use, WWTP discharges into a saline prairie
Beni and Pando	265	No wastewater use, high rainfall zones
Tarija	248	Indirect use of polluted water from Guadalquivir river
Sucre	217	No data available
Potosi	238	No data available

opinion about the advantages (availability, nutrients) and disadvantages of such use. In the situation of indirect use, however, the irrigators consider that the pollution of the river damages their agricultural activities.

Wastewater Use in and Around Cochabamba

The downstream area of Cochabamba known as La Mayca is served by the Sistema Nacional de Riegos No. 1 (SNR-1) Irrigation Scheme. Before 1980, this Scheme received its irrigation water from the Angostura Dam and partly from the small Rocha river that crosses Cochabamba. Since the construction of a new airport, part of SNR-1 was cut off from these supply sources. To solve this, the farmers agreed with SEMAPA to irrigate with effluent from the Alba Rancho facultative stabilisation pond treatment plant, constructed in 1986 that has a design capacity of 400 l/s. Other farmers depend more on the water from the Rocha river and from two smaller rivers, the Tamborada and the Valverde. These rivers, however, have increasingly been polluted due to the growing urban population and the uncontrolled discharge of industrial and domestic wastewater. Actually, in the dry season the natural water flow of the river is virtually zero, which means that almost all the discharge is domestic and industrial wastewater.

The irrigated area downstream of Cochabamba can be divided into several zones, each of which uses a different mix of water, depending on location, season and general water availability (Fig. 12.1 and Table 12.3). Most water flows by gravity, although in some places it is pumped to irrigate fields located higher up the valley. Some farmers have a choice between water sources, including wells, depending on water availability.

In the entire area surface flood irrigation is practised. Average farm size ranges from 1–5 ha. The farms have a relatively high cattle density at 12 animals per family. The milk is mostly delivered to Cochabamba dairies although farmers increasingly process part of their milk production into cheese.

Apart from alfalfa and fodder grass (*Lolium* sp.), maize, potato and beans are cultivated. However, due to increasing salinisation in the area, farmers are increasingly shifting to *Lolium* fodder grass that is salt-tolerant. Some plots are no longer cultivated because of soil degradation.

Because all farmers do not use rubber boots and gloves for protection during irrigation, this results in infections. Farmers in this area do not

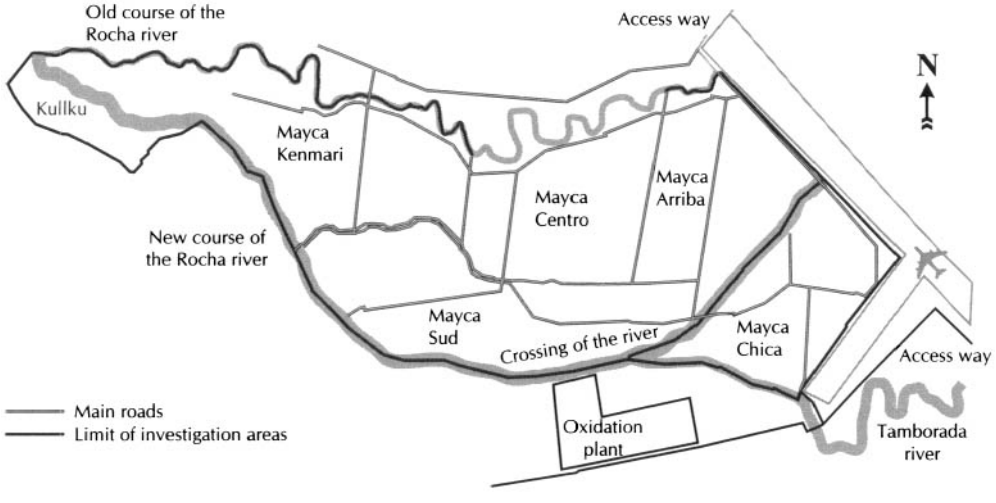

Fig. 12.1. Map of the La Mayca irrigated area downstream Cochabamba, Bolivia.

Table 12.3. Area irrigated (ha) from different sources depending on water availability in La Mayca, Cochabamba.

Community	Water source					
	Angostura Dam (1st choice)	Treated water from Alba Rancho	Rivers			Total irrigated area
			Tamborada	Rocha	Valverde	
Monte Canto	10	30				40
Champarrancho	0–8	0–8	0–8			8
Tamborada B	0–15	0–15	0–15			15
Tamborada C	0–17	0–17				17
Mayca Chica	–	0–10		140–150		150
Mayca Sud	11–143	0–110		0–22		143
Mayca Quenamari	0–77	0–77			0–77	77
Media Luna	–	21				21
San José	0–38	0–38				38
Albarrancho	0–114	0–114				114
Kullko	–	57				57
Mayca Norte	60–400	0–100		0–160	0–80	400
Mayca Central	160–350	0–50		0–140		350
Pampa López		28				28
Quenamary		42				42
Sumunpaya	22–77	0–55				77
Total	253–1,249	178–772	0–23	140–472	0–157	1,578

Source: Consultora Galindo Ltda., 2001.

Table 12.4. Quality of water from different irrigation sources in La Mayca, Cochabamba.

Parameter	Allowed limits (Bolivian standards for water pollution)	Sample[a]					
		Rocha river + sewage M - 1	Rocha river – sewage M - 2	Rocha river + WWTP M - 3	Rocha river + WWTP + sewage M - 4	WWTP M - 5	SNR N1 Angostura Dam M - 6
Electric conductivity (mhos/cm)	Not specified	1057	798	1508	1809	1594	391
N – NO_3 mg/l	< 5	0.016	n.d.[c]	n.d.	0.013	n.d.	n.d.
N – NH_3 mg/l	< 5	102.3	26.4	n.d.	93.7	n.d.	n.d.
Cr^{6+b} mg/l	0.05	< 0.02	< 0.02	< 0.02	n.d.	n.d.	n.d.
BOD_5 mg O_2/l	< 2[d] < 5[e]	319	71	176	96	109[f]	n.d.
Total coliform MPN/100 ml	Not specified	4.4×10^6	3.5×10^6	4.3×10^6	8.6×10^6	1.5×10^7	3.9×10^4
Faecal coliform MPN/100 ml	< 1000	3.2×10^6	1.9×10^6	4.1×10^6	5.8×10^5	3.5×10^5	1.0×10^3

Source: Agreda, 2000.

[a] Samples taken at different dates during the dry season: September–November, 1999.

[b] The analyses for heavy metals included those for lead and cadmium. These metals were not detected.

[c] No data available.

[d] For crops consumed raw.

[e] For processed crops and fodder.

[f] Data from SEMAPA.

complain about their health, yet 80% of them are known to have skin mycosis (Agreda, 2000).

The data in Table 12.3 show that, of a total irrigated area of 1,578 ha almost 50% is wastewater-irrigated in dry years and up to 40% with polluted surface water from small rivers. Only 16% of the area (253 ha) is assured of freshwater from the Angostura Dam in a dry year.

Table 12.4 gives water quality data as measured in this region. Farmers complain about the quality of irrigation water, specifically, about the degradation of their plots through salinisation. The industrial discharge (from tanneries) and the increasing use of wastewater might well be a cause for this, although the effects of the poor internal and external drainage of the area and the excess water applied to the fields should also be considered.

The inflow to the treatment plant exceeds the design capacity by almost 50%. The high inflow load and poor dilution of waste concentrations resulting from the low *per capita* average daily water consumption of 80 l result in the poor quality of the WWTP effluent.

Even though there are strict by-laws that forbid this, industries discharge their wastewater without treatment into the domestic sewerage system or directly into the surface water. This is an important environmental threat, and has already led to a build up of heavy metals in the soil profile, with extremely high concentrations of cadmium (Cd), chromium (Cr^{6+}), and lead (Pb) (Table 12.5).

During a field visit in October 2002 it was observed that wastewater is also used in the upstream parts of the city, immediately downstream of some housing areas that have been provided with communal primary treatment facilities (Imhoff tanks) at some distance from the housing. The main objective of an Imhoff tank is to reduce the suspended solids load in the receiving surface water. Because of the design of the Imhoff tank system there is no further treatment of waste at the secondary level. The local community was asked to assign and pay a person to maintain these primary treatment systems. But, the community has no incentive to maintain the systems, and consequently they malfunction. As a result, sewage water is now being discharged into open drains and subsequently used for small-scale irrigation, including vegetables.

Institutional Aspects

The use of (treated) wastewater in (peri-)urban agriculture is directly linked to urban water supply, sanitation and wastewater treatment capacity since water-supply organisations are also usually responsible for sewerage and wastewater treatment. In Bolivia, different institutions have a role to play (Durán *et al.*, 2003):

- The Ministry of Housing and Basic Services (Ministerio de Vivienda y Servicios Básicos) includes among its responsibilities: the definition of sector policies and priorities, formulation of norms and regulations for the sector, planning sector development, promotion of research and human resources development programmes, channelling of financing and investments, the establishment of a sector-wide information system, and the supervision of the Superintendent of Basic Sanitation (see below).
- The Ministry of Sustainable Development and Planning (Ministerio de Planificación y

Table 12.5. Occurrence of heavy metals (mg/kg dry soil) in soil of the La Mayca area, Cochabamba, Bolivia (Agreda, 2000).

	Mayca area soil profiles					
	A-102		A-104		A-105	
Sample depth (cm)	0–29	29–60	0–28	28–51	0–23	23–40
Cadmium	93	118	38	31	124	120
Chromium	22	14	12	11	12	14
Lead	1500	1313	806	1235	687	1076

Table 12.6. Estimated wastewater production in 2020, based on population data for various Bolivian cities (Durán *et al.*, 2003).

City	Growth (%)	Urban population ('000)		Wastewater discharge (l/s)[b]		Annual volume (Mm^3)	
		2001	2020[a]	2001	2020	2001	2020
Cochabamba	4.2	855	1,865	634	1,382	20	44
Sucre	4.2	217	472	161	354	5	11
La Paz	2.8	1,550	2,629	1,147	1,948	36	61
Oruro	0.7	237	272	176	202	6	6
Potosi	1.0	238	286	176	212	6	7
Tarija	4.8	248	599	183	444	6	14
Santa Cruz	4.9	1,543	3,816	1,143	2,827	36	89
Beni	3.1	244	439	181	325	6	10
Pando	8.0	21	91	16	68	<1	2
Total		5,153	10,470	3,817	7,762	122	244

[a] Authors' estimate.

[b] Estimated discharge $Q = cPD/86400$ where: c = discharge coefficient (0.8), P = population, and D = water supply per capita (average value: 80 l/day).

Desarrollo Sostenible), in coordination with the Ministry of Housing and Basic Services, plays a role in the formulation and application of the environmental norms related to water supply and sanitation. It also oversees water quality.

- A Superintendent of Basic Sanitation (Superintendencia de Saneamiento Básico, SIASAB) is mandated to regulate water supply and sanitation services in the urban and rural sectors. In particular, SIASAB oversees the quality of service provision, approves tariffs according to sector regulations, grants concessions from customers, and applies fines.
- The Prefectura, with responsibility at the Department level for formulating investment projects, plans service expansion programmes and projects, supervises works, and provides technical assistance to the service companies. It actually works mainly in the rural areas.
- The Popular Participation Law and the Law of Municipalities transferred ownership and operational responsibility for provision of water supply and sanitation services to municipal governments, enlarging their roles and responsibilities. It is also the Municipal governments' task to develop plans and programmes for the expansion of water supply and sanitation services, in coordination with the Prefectura.

Presently, there are four types of institutional arrangement for the management of water supply and sanitation:

- **Cooperatives:** of which there are 120, mainly in Santa Cruz and Tarija
- **Autonomous municipal companies**: the main ones being in Cochabamba (SEMAPA), Sucre, and Potosí
- **Concessions with the private sector**: which only exist in La Paz and El Alto (Aguas del Illimani). This model provoked great social conflicts in the city of Cochabamba after its introduction in 1999 and the company (Aguas del Tunari) was forced to withdraw in April 2000, handing back the administration to SEMAPA.
- **Water committees:** formed with contribution and participation at the neighbourhood level.

Costs for wastewater treatment are included in the price of drinking water, which is already high in Cochabamba (US\$0.23/m^3) compared to the prices charged by other (rural) drinking water suppliers (US\$0.10–0.20/m^3), who only recover operational costs. The tariff for sewerage and wastewater treatment varies from 40–65% of the drinking water price. Although people seem to be aware and prepared to pay for wastewater treatment, a recent decision to further increase the drinking water price to allow more and better treatment had to be withdrawn, after violent protests by the

Cochabamba city population. This is a significant backwards step in improving the water quality for the irrigators, if indeed wastewater treatment were to be made effective.

The general lack of urban planning and management capacity in Cochabamba affects this situation. The municipal authorities have not been capable of steering the rapidly expanding city. Comparing the state of the Rocha river now to its situation in the 1990s reveals major differences in discharge and water quality (A.M. Romero, Cochabamba, 2002, personal communication). Cochabamba has also been confronted with uncontrolled housing construction that has certainly increased water pollution. There is a clear lack of land use planning that should cope with the growth in wastewater and its management. In Bolivia, water is available for those people who have established water rights that are closely linked to irrigation. This automatically means that people and institutions without such traditional rights have limited access to (good quality) water.

Agricultural Potential

A significant area in and around Cochabamba currently depends on untreated and treated wastewater for irrigation, especially in the dry years. In the coming 20 years, the volume of wastewater is expected to double (Table 12.6) and those farmers that have no or insufficient access to other water sources will certainly try to use wastewater. Although wastewater is of inferior quality because of its high salt contents and possibly even contains toxic elements, the farmers will first consider that it is the most reliable source of water. Contrary to supplies of surface water or water from a formal irrigation scheme, wastewater flow is increasing in volume and is available all year round.

Discussion and Conclusions

Treated domestic wastewater should be considered as a valuable source of water for irrigated agriculture. If well managed, such use is productive, cost-effective and environmentally safe. However, the way wastewater is actually used in Cochabamba is far from ideal and poses a number of health risk and environmental pollution problems. To avoid an environmental crisis, several things need immediate action.

The wastewater flow in Cochabamba partly originates from industries, including tanneries. This wastewater contains salts and such toxic elements as chromium (Cr^{6+}), that are harmful to crop production and/or are polluting the environment. As a first and immediate step, industries should be forced to reduce the contaminant load in their discharge by, for example, pre-treating their wastewater before discharging it. Special attention should be given to industries like the tanneries that discharge high quantities of soluble salts which degrade soils in the downstream irrigated area by rendering them saline.

Investments are required to improve the drainage of lower-lying areas. Observed salinity problems should also be studied in relation to the irrigation techniques used. A change in these techniques (possibly in combination with a change in the types of crops cultivated) might help to reduce this problem. However, such modern irrigation techniques as micro-irrigation, are expensive and do not completely reduce the risks of salinisation. It should be realised that irrigation with moderately saline water is possible so long as there is appropriate drainage for leaching. This would, however, transfer the salts to the drainage water that would undoubtedly be discharged again into the river.

An increase in the city's water treatment capacity is badly needed. In developing this capacity, care should be taken to invest in appropriate technology that can be managed within the limited available financial and managerial resources. In other countries, like Brazil, Colombia, and India, systems such as the upflow anaerobic sludge blanket (UASB) have been developed; these are not dependent on electricity and can provide adequate contaminant reduction with minimal maintenance (van Lier and Lettinga, 1999).

The present situation calls for a decentralised water treatment approach, given the fact that wastewater is produced and used for irrigation in different areas in and around the city. Decentralised systems can be initiated far more rapidly than large capital-intensive centralised treatment plants. In the Brazilian city of

Recife a decentralised approach has been officially included in the sanitation and sewerage master plan of the city (Florencio and Kato, 2001). The Water and Environmental Sanitation Centre, [Centro de Aguas y Saneamiento Ambiental (CASA)], of Cochabamba, could play an important role in technology choice, with specific attention to the requirement for low-maintenance systems If maintenance of the decentralised systems depends on local community initiative, then the community should also benefit from its investment. This means that farmers from the same community that treats the wastewater should be able to use the treated effluent.

An integrated water management (IWM) approach is surely needed to improve the present situation in Cochabamba. Farmers who now have direct access to wastewater flows and those just beyond are irrigating with water of extremely different qualities. An irrigation supply system that would allow mixing of water from different sources to manage the high salt content should be considered. At the same time, sanitation, wastewater treatment, and subsequent agricultural use should be based on a conceptual design framework in which the water flow from source to irrigation and drainage is subject to holistic management that also considers cost-effectiveness and environmental issues (Martijn and Huibers, 2001). An interdisciplinary and participative approach is needed. In common with most of Latin America, the Bolivian irrigators are organised in such a way that they represent themselves well in negotiations and could be partners in a design process.

Creating awareness among actors, building management capacity, extension, and communication are all seen as important ways to improve the present situation and to support future development.

Irrigated farming around Cochabamba presents an example of a degrading agricultural system caused by water pollution particularly that resulting from uncontrolled discharge of industrial liquid waste into surface water, and the use of irrigation techniques without drainage required to effectively manage the poor water quality.

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13 Treatment Plant Effects on Wastewater Irrigation Benefits: Revisiting a Case Study in the Guanajuato River Basin, Mexico

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Abstract

In 1999 field research was carried out to explore the advantages and risks of urban wastewater use for 140 ha of crop production in the Guanajuato River basin. It was found that wastewater which was freely available to the farmers represented an important additional source of irrigation water, with secondary benefits including nutrients and the foregone cost of wastewater treatment. In 2002, the urban water supply and sanitation utility, a financially autonomous public utility, began to operate an activated sludge wastewater treatment plant in response to the imposition of legally mandated fines for the release of untreated wastewater to open water bodies. As follow-up to the 1999 study, this chapter is based on field visits and interviews and sets out to qualitatively answer the following research question: Does the introduction of wastewater treatment influence the crop production benefits of wastewater irrigation? The study found that because wastewater treatment was oriented to comply with environmental regulations, little attention was paid to the links with the land irrigated by wastewater. The presence of the treatment plant provides the utility with the option of selling treated wastewater, thus increasing its own economic benefits. Industrial users appear to be the most suitable potential customers; the utility would stand to receive US$0.43/m^3 in estimated sale price plus saving the US$0.25/m^3 fine. This transfer of water would introduce competition among water-use sectors, a process that is already leading to wastewater farmers' uncertainty about their future share of irrigation water. However, to date no commercial transaction to transfer treated wastewater to non-agricultural users has taken place. For this reason the expected changes in impacts on wastewater farmers have been minimal. If this happens, however, the wastewater farmers stand to lose because only about 30% of the wastewater-irrigated land has a water concession title (linked to the land) issued by federal authorities.

Introduction

In 1999 field research was carried out by Scott *et al.* (2000) to explore the advantages and risks of urban wastewater use for crop production in the water-short Guanajuato River basin in west-central Mexico where at least 140 ha of land were irrigated with raw wastewater downstream of the city of Guanajuato[1] in two peri-urban communities: San José de Cervera

[1] Guanajuato is the name of the state as well as its capital city (and the river that runs through it). Unless otherwise indicated, Guanajuato here refers to the state not the city.

 Wastewater Use in Irrigated Agriculture
(eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

and Santa Catarina. Findings showed that wastewater represented an important additional source of irrigation water, with secondary benefits including nutrients and the foregone cost of wastewater treatment. It was stated that 'wastewater irrigation is a critical component of intensive water recycling in the Guanajuato River basin, based primarily on the value of the water resource and the nutrients it transports. The land irrigated with raw wastewater downstream of the city serves as *de facto* water treatment with significant retention of contaminants' (Scott *et al.*, 2000). The study did not measure the environmental costs and risks associated with untreated wastewater irrigation, which if adequately quantified would reduce the overall benefits. The study did address health risks but was unable to draw firm conclusions based on: a. the difficulty in establishing clear causal links between wastewater quality and health, and b. insufficient data on diarrhoea incidence.

Wastewater irrigation and discharge to open water bodies – in Mexico all rivers, lakes, wetlands, and groundwater are considered public property under federal jurisdiction – are subject to the maximum allowable contaminant limits established in the environmental regulation NOM-001-1996.[2] This regulation also establishes a fine of US$0.25/m^3 of untreated wastewater discharge that exceeds the permitted limits. In accordance with this national policy, urban water supply and sanitation utilities across the country constructed wastewater treatment plants using a timeframe based on the population size of the city. In June 2000 the Guanajuato city utility called the Sistema de Agua Potable y Alcantarillado de Guanajuato (SIMAPAG) (in English, the Guanajuato Water Supply and Sanitation Board) undertook the construction of an activated sludge plant to treat all the wastewater discharge from the city centre. The treatment plant started operating in June 2002. This chapter addresses the changes in wastewater irrigation in the Guanajuato River basin that are occurring as a result of the treatment plant. It attempts to provide qualitative answers to the research question: 'Does the introduction of wastewater treatment influence the crop production benefits of wastewater irrigation?'

The need to assess the effects of the introduction of wastewater treatment on downstream irrigation is essential due to the rapid implementation of wastewater treatment in Mexico, a country where unregulated wastewater irrigation is prevalent. In addition, the experience of a middle-income country in converting from untreated to treated wastewater use provides important lessons for low-income countries that are considering wastewater treatment. Backed by the national environmental laws and state policies, treated wastewater volumes will increase in Mexico and as a consequence, the use and management of wastewater irrigation will change. For instance, in Guanajuato 87% of its wastewater should be treated by 2005 compared to the current 57% (CEAG, 1999). In this state alone, approximately 20,000 ha (5% of the 416,690 ha irrigated in the state) could be irrigated using the 207 million m^3 of wastewater currently generated annually in the state's 46 municipalities.

The first part of the chapter consists of a general overview of the Guanajuato River followed by a brief description of the salient characteristics of SIMAPAG and its wastewater treatment plant. In the second part the use of wastewater in agriculture and its consequences in the state of Guanajuato are reviewed, followed by a discussion of the treatment plant's impact on urban wastewater use for crop production. Finally, lessons learned and policy recommendations are presented.

The Guanajuato River Basin

The Guanajuato River constitutes a sub-basin to the Lerma–Chapala Basin. It encompasses the municipalities[3] of Guanajuato, Silao, Irapuato

[2] Having followed the procedures established in the Federal Law on Methodology and Regulations to formulate Mexican Official Regulations, the National Consultative Committee on Environmental Protection Regulations, on 30 October 1996, passed the Mexican Official Regulation (in Spanish, Norma Oficial Mexicana, NOM) NOM-001-ECOL-1996.

[3] In Mexico, the municipality is the next political and administrative level below the state and encompasses both the urban or town centre and the surrounding rural areas.

and Romita. The wastewater produced in these cities, estimated at 1 m^3/s, receives varying levels of treatment – from secondary treatment in Irapuato to none at all in smaller urban centres like Romita. As a result, the 12-km reach of the Guanajuato River from the city to La Purisima reservoir is highly contaminated with organic loads, bacteria and inorganic pollutants. In this reach, untreated wastewater is diverted for irrigation purposes. During the field work of 1999, the irrigation diversions for the two peri-urban communities, San José de Cervera and Santa Catarina, were studied in depth (Scott *et al.*, 2000). One important characteristic of this relatively small sub-basin is the presence of multiple water and nutrient recycling loops. Based on flow measurements of the total river discharge of 0.305 m^3/s flowing out of the study reach over half (0.162 m^3/s) was comprised of return flows. This means that the sub-basin's limited water resources could be managed to satisfy multiple demands.

National Water Commission (CNA) data show that from 1992 to 1999, water quality in the Guanajuato River further downstream of the larger city of Irapuato, but above its confluence with the Lerma River, deteriorated significantly (CNA, 2000). According to these data, the Guanajuato River is considered contaminated for agricultural uses.

SIMAPAG and the Wastewater Treatment Plant

In order to better understand options for wastewater management it is critical to review the basic features of the water supply and sanitation utility. One of a total of 31 water supply utilities in the state of Guanajuato, SIMAPAG supplies municipal water and manages sewerage in the city of Guanajuato (total population around 106,000). SIMAPAG is a financially autonomous public utility with an independent administration that is subject to regulatory oversight by a governing council of municipal representatives and citizens who are appointed by the elected municipal government. The SIMAPAG governing council appoints the utility's general manager and approves the budget including water and sanitation fees.

At the state level, water supply coverage is over 95% of the urban population and 75% of the rural population. In recent years, the growth in number of connections has consistently exceeded population growth (Fig. 13.1) indicating that urban water supply coverage will soon reach 100%. The relevance of these data is that wastewater volumes will continue to grow at rates faster than urban population growth. Many of the federal programmes to support municipal water utilities are not expressly oriented to increase water supply and sanitation coverage, but instead to rehabilitate infrastructure. This only permits increased coverage indirectly.

In 2001, Guanajuato city's potable water supply level was 95% and the sewerage coverage level was 82%. Domestic connections represented almost 94% of the total water connections. Meters (some 25,000 in total) are installed on all connections allowing the utility to estimate wastewater discharge by household. The average monthly consumption per connection was 27.7 m^3 at an average fee of US\$0.59/m^3 (Scott *et al.*, 2000). Sewerage and other non-water supply fees represent 8.3% of the billed amount; this will increase to 10%. SIMAPAG pays the federal government approximately US\$200,000 in water use fees; however, as an incentive federal authorities waived these fees during the period of wastewater treatment plant construction just as they do for other urban water utilities in the process of wastewater treatment implementation.

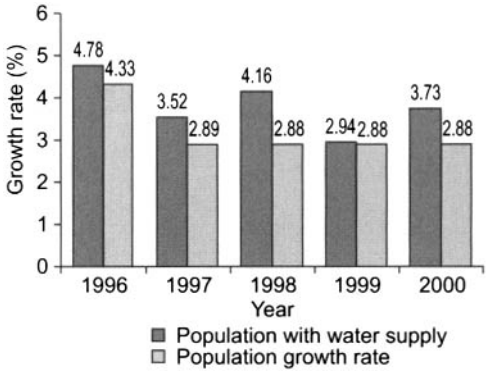

Fig. 13.1. Comparison between population growth rate and increase in water supply coverage in Guanajuato state, Mexico (CEAG, 2001).

In 2002, a financial surplus of US$158,000, or 25% of expenditure, was generated. Subject to the approval of the governing board, surpluses are used for infrastructure improvement and other capital investment. Despite significant outlays to cover SIMAPAG's share of the wastewater treatment plant construction in 2001 and 2002, the accumulated reserves totalled US$1,182,000 at the end of 2002 (Marco Antonio Ortíz, SIMAPAG general manager, personal communication, 2003). Additionally, the overall efficiency (including the physical, commercial and billing efficiency) has varied between 55.8% and 61.2% in the past 4 years. SIMAPAG aims to increase this to a consistent 60%, the benchmark set for receiving performance- based federal support programmes including wastewater treatment.

The total annual wastewater volume generated in Guanajuato's 46 municipalities is 207.13 million m^3. If this water could be used directly for agricultural purposes, around 20,000 ha of grain crops could be irrigated, equivalent to almost 5% of the actual irrigated land in the state (416,690 ha). At the end of 1998, only 25 million m^3/year were treated; however, in the first quarter of 1999, this increased to 34.46 million m^3/year. There are 16 urban wastewater treatment plants and another 26 plants in rural areas. Of the urban plants, at least four are officially recognised as having agricultural use (Irapuato, San Francisco del Rincón, Coroneo and Tierra Blanca). Eleven small rural plants, each with a design discharge of 2–10 l/s, generate treated wastewater used for irrigation. However, there is a declared lack of technical and administrative capacity on the part of many utilities to implement wastewater treatment and cost recovery.

SIMAPAG constructed an activated sludge[4] with chlorine disinfection treatment plant for a total investment cost of US$3.6 million (see Fig. 13.2 and Table 13.1). The federal government contributed 24%, the municipal government 40%, and SIMAPAG the remaining 36% derived from the operating budget surpluses carried forward from past years. According to the average consumption per connection the expected sewage

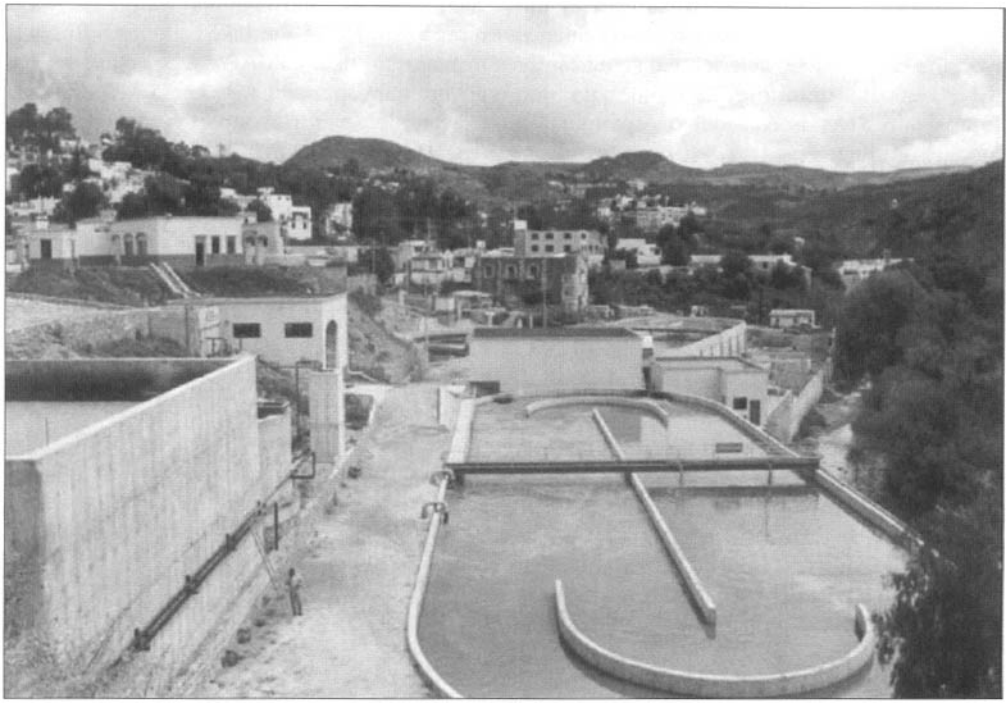

Fig. 13.2. The Guanajuato city wastewater treatment plant

[4]The 1,100 kg of sludge generated daily is landfilled.

Table 13.1. Plant treatment design parameters.

Parameter	Unit	Influent	Effluent
Design discharge	lps	140	140
Total suspended solids (TSS)	mg/l	217	< 60
Total biochemical oxygen demand (BOD_5)	mg/l	337	< 60
Total nitrogen (Kjeldahl)	mg/l	82	< 35
Faecal coliforms	MPN /100 ml	6.2×10^6	< 1000
Total phosphorus	mg/l	11	< 20

discharge[5] from Guanajuato city is 0.14 m^3/s or 12.1 million l/day. Before the wastewater treatment plant started operation, this effluent flowed directly down the Guanajuato River where it was diverted for irrigation. Currently 70% of the total wastewater discharge is treated – the wastewater collector pipe for the treatment plant inlet only covers the main part of the city and does not collect sewage from the neighbouring peri-urban community of Marfil that represents the remaining 30% of wastewater. The wastewater generated in this area continues to flow downstream untreated. SIMAPAG will have to pay some US$470,000 annually in discharge fines unless it makes satisfactory progress in treating this wastewater.

SIMAPAG had four principal motives behind the implementation of wastewater treatment, it aims to:

- Meet the maximum allowable contaminant limits according the National Water Law and comply with discharge regulations or face fines
- Assume responsibility for water quality preservation
- Improve the public health and ecology
- Benefit directly the 81,000 inhabitants who are provided with sewerage coverage.

Urban Wastewater Use for Crop Production and its Consequences

Irrigation with wastewater is a common practice in Guanajuato. According to official records, there are 3,200.4 ha irrigated with wastewater, with a water volume of 19.1 million m^3 (Sánchez, 1995), but there are numerous wastewater irrigation areas that have not been accounted for. One of the most important areas for this kind of irrigation is the area surrounding León, Guanajuato's largest city with a population of approximately 1 million. Starting at least 40 years ago, irrigation with wastewater began in a small area to the south-west of the city and spread southwards with the expansion of the urban area and the consequent greater availability of wastewater (Sánchez, 1995). A considerable volume of wastewater is used in agriculture, with or without federally approved water use rights.[6]

Health and environmental risks have been identified particularly because of the prevalence of chromium derived from Leon's important leather and tanning industries. The risks to exposed populations are dependent mainly on water management and the irrigation methods used (Blumenthal *et al.*, 2000). In León, wastewater is used in furrow irrigation of maize and alfalfa. Similarly, in the Guanajuato city study area only furrow irrigation is used for maize and alfalfa.

Treatment Plant Effects on Wastewater Irrigation Benefits

Benefits of untreated wastewater use

Before the construction of the wastewater treatment plant, a number of wastewater irrigation benefits in the study area were identified.

[5] This figure was estimated based on the 2000 SIMAPAG records of 27.7 m^3/month average consumption and 22,347 connections, and assuming that 70% of the total consumed water per outlet will return as sewage.

[6] All irrigation water users in Mexico are supposed to be listed in the Public Register of Water Rights (Registro Público de Derechos de Agua). Failure to register can entail that water use may be summarily curtailed.

According to Scott *et al.* (2000), the benefits from wastewater irrigation are as follows:

1. The water used for irrigation represents a recycling of urban wastewater in a basin context. Related studies found that irrigation output per hectare is approximately US$1,800, and per cubic metre of water is US$0.16 (1994 dollars) (Kloezen and Garcés-Restrepo, 1998). Therefore, the water value of wastewater used for irrigation represents a significant monetary benefit to both society and the water users.
2. The waste stream has a nutrient value that represents an input that reduces the agriculture production costs. For the case study, the annual gross values of the wastewater and wasteload to farmers in San José de Cervera were estimated at US$252,000 and US$18,900 in Santa Catarina.
3. The continued application of the wastewater to the land would be a more economical form of wastewater treatment than activated sludge treatment and subsequent discharge to the open river where treated water is mixed with untreated discharge further downstream.

These benefits were reassessed in light of the implementation and operation of the new wastewater treatment plant, based on field visits and discussions with the treatment plant manager and the SIMAPAG general manager as well as with farmers from San José de Cervera and Santa Catarina communities.

Impact on water value

The presence of a treatment plant provides SIMAPAG with the option of selling the treated water to whichever sector can afford it; however, no commercial transaction has taken place yet. Various plans to sell water for tourism development, a golf course, an expansion of the University of Guanajuato campus, etc. continue to be considered. This would definitely add value to the water but would also result in greater competition among water users, some of whom have existing rights over the wastewater flow. Findings showed that the operational cost of one m^3 of treated wastewater is US$0.11. By means of a sanitation service charge equivalent to 10% of the billed amount for water supplied, SIMAPAG recovers US$0.04/$m^3$ from domestic users and US$0.08/$m^3$ from industrial and commercial users. Therefore, in order to be profitable the sale price for treated water should be at least US$0.07/$m^3$. Industrial customers could afford to pay up to US$0.50/$m^3$ giving an estimated surplus of US$0.43/$m^3$. Small-scale agriculture could scarcely afford to pay for treatment or for the fine, confirming that the polluters should not expect existing users to pay for treatment. The productivity of small-scale irrigation systems in the area however (around US$0.15/$m^3$ according to Silva Ochoa *et al.*, 2000) is lower than the cost of the untreated wastewater discharge fine (US$0.25/$m^3$) and approximately in the same range as the operational cost of treatment (US$0.11/$m^3$). Higher productivity – up to US$0.50/$m^3$ – could be reached if more profitable crops like vegetables were cultivated, but vegetables and greens consumed raw are not permitted to be irrigated with wastewater in Mexico. From the above analysis it is clear that the treatment plant is not a benefit to the farmers.

Impact on nutrient value

The existing concentrations of total nitrogen (N) and total phosphorus (P) in the effluent are sufficient to meet the nutrient requirements for alfalfa. Considering a 1 m irrigation depth to satisfy the alfalfa nutrient demand, which is equivalent to 88 kg N/ha and 115 kg P/ha, the required concentrations are 9 mg/l for N and 12 mg/l for P, both significantly lower than the design quality of the effluent (Table 13.1). These results concur with what was observed during the field visits; farmers showed very little concern for the reduction of nutrients due to wastewater treatment upstream. Actually, farmers appeared to have little evidence of any treatment taking place because treated and untreated discharges mix in the river downstream of the plant. Improved water quality can only be visually appreciated 4 km downstream of the plant. Further down, a slaughterhouse dumps significant quantities of contaminants in the river. Moreover, in most cases the treated wastewater still has high nutrient concentrations ranging from 20–40 mg

N/l, 20–35 mg P_2O_5/l, and 40–50 mg K_2O/l. As a result, water users' primary concern is that volumes will reduce.

The sludge represents an important source of nutrients; the treatment plant produces 1.1 tonnes of waste solids daily. The storage and elimination of this material is one of the major operational problems faced by the plant. According to the recommended application rate of sludge for agricultural soils (15 t/ha per year), the total area that would benefit from the wastewater treatment is 30–50 ha, which is only around 20–30% of the total wastewater use area. Unfortunately, the solid waste is taken to a landfill. Because Guanajuato has no major industry, heavy metals are not a problem (the 1999 study found that heavy metals were within US and European norms).

Impact on foregone treatment costs

It appears obvious that wastewater irrigation was not considered as an alternative method for wastewater disposal. The definitive guideline for the selection of the wastewater treatment process was the environmental regulations described in NOM-001-1996. The possibility of using wastewater irrigation as a complementary process for wastewater treatment was not considered. However to make this a viable option the total land area required for this purpose should have water rights, which is not the case at present (most of the land currently irrigated with wastewater does not hold an officially recognised right). Annually, there are 300,000–500,000 m^3 of water that is legally granted, which represents just 30–50 ha of irrigated land.

From SIMAPAG's perspective, the wastewater treatment plant should be oriented to the use of treated wastewater in various types of landscape irrigation, i.e. golf courses and parks, where the maximum allowable limits are higher than those for agriculture. At present there is no concern to treat wastewater specifically for the requirements of the pre-existing use, which is irrigation. SIMAPAG seeks to treat water to the level required to avoid the fine and to sell treated water in order to recuperate the capital investment. The cost and difficulty in operating and maintaining a conventional treatment plant to produce effluent that meets the limits for irrigation are too high for agriculture to bear. This represents a clear case for the 'polluter pays' principle.

Conclusions and Recommendations

Wastewater treatment in Guanajuato city has been implemented despite the lack of an integrated framework for its use or for wastewater management in a larger basin context. The ideal outcome of wastewater treatment would be to increase the benefits of municipal water users and the utility as well as those of agricultural and other (potential) wastewater users. Nevertheless, Guanajuato's wastewater treatment project was oriented to meet environmental regulations and little attention was paid to the links with existing wastewater use for irrigation. As a result, the immediate benefit from the implementation of wastewater treatment is simply to avoid the pollution fine. Strictly from the financial perspective, this is cause enough to treat the city's wastewater.

The major impact of treatment for the users of wastewater is the possible reduction in the water discharge in the river if the treated water is sold to non-agricultural customers either inside or outside the Guanajuato River sub-basin. While there has been speculation that the General Motors automobile assembly plant in the adjoining Silao River sub-basin is looking for additional sources of water, at present the purchase and piping of water appear to be prohibitively expensive. Farmers are in a weak position to defend their access to the wastewater flows given that only 30–50 ha have a water entitlement.

There is little or no expected impact on the nutrient value resulting from treatment, given that the nutrient requirements of the principal crop, alfalfa, would continue to be met even after treatment. Additionally, other sources of untreated urban wastewater enter the river downstream of the treatment plant, entailing sufficiently high nutrient loads that little effect of treatment was perceptible to the farmers. The benefits from the waste solid sludge are being lost because these go directly to a landfill instead of being spread on agricultural land.

Further research is needed to identify conditions under which the substantial benefits of

wastewater irrigation can be captured while financial sustainability of the water supply and sanitation utilities is maintained. The following issues need to be addressed in further detail:

- The conditions required for wastewater markets to function, specifically commercial feasibility for irrigation use of treated vs. untreated wastewater, pricing and supply mechanisms, etc.
- Water rights conflicts
- Hydrological impact of selling the treated water outside the sub-basin
- Water quality assessment of the final use, e.g. at the farm level for irrigation
- Accounting for the nutrients lost in the treatment process.

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14 From Wastewater Reuse to Water Reclamation: Progression of Water Reuse Standards in Jordan

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Abstract

Jordan has worked to manage irrigation with wastewater for several decades. Since the early 1980s the general approach has been to treat the wastewater and either discharge it to the environment where it mixes with freshwater flows and is indirectly reused downstream, or to use the resulting effluent to irrigate restricted, relatively low-value crops. Given the diminishing per capita freshwater supply, the increasing dominance of effluent in the water balance, the overloading of wastewater treatment plants, local riparian water rights, and the need to protect domestic and export produce markets, effectively managing water reuse, including enforcement of existing regulations, has become increasingly challenging. Jordan is in the process of rehabilitating and expanding its wastewater treatment plants, and exploring options for smaller communities. Reclaimed water, appropriately managed, is viewed as a major component of the water resources supply to meet the needs of a growing economy. Appropriate standards and guidelines for water reuse are an important requirement. The previous water reuse standards were reviewed, a working framework developed, stakeholder participation sought and input provided to the formal process for adopting the new standards. The revised standards allow for a wide range of water reuse activities including, where economic conditions allow, highly treated reclaimed water for landscapes and high-value crops, and for lower cost smaller-scale treatment and reuse activities with restricted cropping patterns.

Introduction

This chapter describes the updated water reuse standards in Jordan and the process that led to their adoption.

The terminology used in this chapter, **water reuse**, is intended to convey what may be understood variously as water reclamation, water recycling, wastewater reclamation, wastewater use, and wastewater reuse in different parts of the world. However, water reuse, as used here, specifically refers to a well-regulated and controlled use of properly treated and conveyed effluent after treatment of wastewater in well-designed and maintained treatment systems. Unplanned water reuse may be properly labelled wastewater reuse.

 Wastewater Use in Irrigated Agriculture (eds C.A Scott, N.I. Faruqui and L. Raschid-Sally)

Wastewater has been used for irrigation in Jordan for several decades. Some treated effluent has been used directly on restricted crops of relatively low value, but the main practice has to been to discharge effluent to the environment where it mixes with freshwater flows before being used indirectly downstream. With dropping per capita freshwater availability, the increasing dominance of wastewater in the water balance, insufficient wastewater treatment capacity, and the need to protect domestic and export produce markets as well as local riparian water rights, managing water reuse and enforcing existing regulations have become increasingly challenging.

Previous Water Reuse Standards

The previous Jordanian Standards for Water Reuse (JS893/1995) were introduced in 1995, prior to which the World Health Organization (WHO, 1989) *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture* had been used (Nazzal *et al.*, 2000). Listing 47 specific constituents, JS893/1995 prescribed limits for each of the seven following uses of reclaimed water.

1. Irrigation of vegetables eaten cooked
2. Irrigation of fruit trees, forests, industrial crops, and grains
3. Discharge to streams and catchment areas
4. Artificial recharge of groundwater
5. Use in aquaculture (fish hatcheries)
6. Irrigation of public parks
7. Irrigation of fodder

JS893/1995 prohibited the following:

- Irrigation of crops eaten raw (tomato, cucumber, carrot, lettuce, radish, mint, parsley, pepper, cabbage, cauliflower, etc.)
- Irrigation during the last 2-week period before harvest
- Use of fruit fallen to the ground
- Deterioration of soil properties
- Use on crops sensitive to constituents of reclaimed water
- Sprinkler irrigation
- Transport of reclaimed water in unlined channels across recharge areas
- Dilution of reclaimed water with freshwater to meet the criteria
- Use of reclaimed water to recharge aquifers used for drinking water supplies.

JS893/1995 standards for reuse and discharge in different media are presented in Table 14.1 and for comparison with the updated Standard and Guidelines (Table 14.2).

Limitations of previous standards

The JS893/1995 Water Reuse Standard tried to regulate both water reuse and environmental discharges, so it was necessary to establish discharge requirements for treatment plants irrespective of, and in addition to, the standards for specific uses of reclaimed water.

JS893/1995 prohibited the recharge of groundwater used for drinking with reclaimed water, but the Jordan Water Strategy (MWI, 1997) specifically includes groundwater recharge as one of the desirable uses of reclaimed water. Updating the Standard attempted to resolve this discrepancy, but, it was clear that protecting the drinking water supply remained an over-riding concern of stakeholders.

JS893/1995 included a long list of constituents, some of which are relevant to environmental protection while others are relevant to water reuse. However, many of the listed parameters had little or no direct public health significance with regards to water reuse.

The export market for food crops grown in Jordan has suffered from restrictions imposed by some of the importing countries of the Arabian Peninsula and Persian Gulf because wastewater, or inadequately treated wastewater, is used to irrigate crops in some parts of Jordan. More recently, standards for exporting crops to Europe have become more rigorous, stressing the importance of addressing the role of wastewater in the water used for irrigation. To address this, the Government of Jordan (GoJ) is implementing an aggressive campaign to rehabilitate and improve the wastewater treatment plants in the country. Of primary importance is the need to establish reasonable standards to protect the health of farmers and the consuming public from infectious agents that can possibly be carried by inadequately treated wastewater.

Table 14.1. Existing (JS893/1995) numerical standards for use of treated wastewater in Jordan (Government of Jordan, 1995).

Quality parameter (mg/l except otherwise indicated)	Vegetables eaten cooked	Fruit trees, forestation, industrial crops and grains	Discharge to *wadis* and catchment areas	Artificial recharge	Fisheries[a]	Public parks	Fodder[b]
BOD5[c]	150	150	50	50	NA	50	250
COD	500	500	200	200	NA	200	700
DO	> 2	> 2	> 2	> 2	> 5	> 2	> 2
TDS	2,000	2,000	2,000	1,500	2,000	2,000	2,000
TSS	200	200	50	50	25	50	250
pH	6–9	6–9	6–9	6–9	6.5–9	6–9	6–9
Colour (PCU)[d]	NA	NA	75	75	NA	75	NA
FOG	8	8	8	Nil	8	8	12
Phenol	0.002	0.002	0.002	0.002	0.001	0.002	0.002
MBAS	50	50	25	15	0.2	15	50
NO_3-N	50	50	25	25	NA	25	50
NH_4-N	NA	NA	15	15	0.5	50	NA
T-N	100	100	50	50	NA	100	NA
PO_4-P	NA	NA	15	15	NA	15	NA
Cl	350	350	350	350	NA	350	350
SO_4	1,000	1,000	1,000	1,000	NA	1,000	1,000
CO_3	6	6	6	6	NA	6	6
HCO_3	520	520	520	520	NA	520	520
Na	230	230	230	230	NA	230	230
Mg	60	60	60	60	NA	60	60
Ca	400	400	400	400	NA	400	400
SAR	9	9	9	9	NA	12	9
RC[e]	0.5	NA	NA	NA	NA	0.5	NA
Al	5	5	5	1	NA	5	5
As	0.1	0.1	0.05	0.05	0.05	0.1	0.1
Be	0.1	0.1	0.1	0.1	1.1	0.1	0.1
Cu	0.2	0.2	0.2	0.2	0.04	0.2	0.2
F	1.0	1.0	1.0	1.0	1.5	1.0	1.0
Fe	5.0	5.0	2.0	1.0	0.5	5.0	5.0
Li	2.5	5.0	1.0	1.0	NA	3.0	5.0
Mn	0.2	0.2	0.2	0.2	1.0	0.2	0.2
Ni	0.2	0.2	0.2	0.2	0.4	0.2	0.2
Pb	5.0	5.0	0.1	0.1	0.15	0.1	5.0
Se	0.02	0.02	0.02	0.02	0.05	0.02	0.02
Cd	0.01	0.01	0.01	0.01	0.015	0.01	0.01
Zn	2.0	2.0	15	15	0.6	2.0	2.0
CN	0.1	0.1	0.1	0.1	0.005	0.1	0.1
Cr	0.1	0.1	0.05	0.05	0.1	0.1	0.1
Hg	0.001	0.001	0.001	0.001	0.00005	0.001	0.001
V	0.1	0.1	0.1	0.1	NA	0.1	0.1
Co	0.05	0.05	0.05	0.05	NA	0.05	0.05
B	1.0	1.0	2.0	1.0	NA	3.0	3.0
Mo	0.01	0.01	0.01	0.01	NA	0.01	0.01
FCC (MPN/100 ml)[f]	1,000	NA	1,000	1,000	1,000	200	NA
Pathogens	NA	NA	NA	NA	100,000[i]	nil	NA
Amoeba and *Giardia* (cyst/l)[g]	< 1	NA	NA	NA	NA	nil	NA
Nematodes (eggs/l)[h]	< 1	NA	< 1	NA	NA	< 1	< 1

[a] depends on fish type, pH, TDS, and temperature.

[b] Trace elements and heavy metals values assume annual irrigation of 10,000 m^3/ha

[c] BOD5 in waste stabilisation pond is filtered, but in mechanical treatment plant is nonfiltered

[d] Unit weight measured by unit of Platen Cobalt

[e] Contact time > 30 min

[f] Most probable number/100 ml

[g] One cyst/l

[h] Mean *Ascaris, Enclostoma,* and *Trycus*

[i] *Salmonella*/100 ml

BOD5 = Biochemical oxygen demand (Five Day)
COD = Chemical oxygen demand
DO = Dissolved oxygen
FCC = Faecal coliform count
FOG = Fat, oil and grease
MBAS = Methylene blue active substance
RC = Residual chlorine
SAR = Sodium adsorption ratio
TDS = Total dissolved solids
TSS = Total suspended solids
T-N = Total nitrogen
NA = Not applicable

Existing Water Reuse Practices

More than 70 million m^3 of reclaimed water, around 10% of the total national water supply, is used either directly or indirectly in Jordan each year (McCornick, 2001). The categories of use are: a. planned direct use within or adjacent to wastewater treatment plants (WWTPs), b. unplanned use in the *wadi* (a dry stream bed or the valley in which such a stream bed is located), and c. indirect use after mixing with natural surface water supplies and freshwater supplies downstream, primarily in parts of the Jordan Valley.

Direct water reuse

The use of reclaimed water at sites in the immediate vicinity or adjacent to the WWTPs is generally under the jurisdiction of the Water Authority of Jordan (WAJ), which plans, builds, owns, operates and maintains the WWTPs. A number of these sites are pilot projects with some research and limited commercial viability, but more recent projects funded by the United States Agency for International Development (USAID), are aimed at developing more productive use of the water resources while demonstrating public health and environmental protection. Other direct water reuse operations, such as the date palm plantations that receive reclaimed water from the Aqaba WWTP, are separate and viable enterprises. Farmers growing crops in these areas – under special contracts with WAJ – are generally satisfied with the water and continue to renew their contracts.

Unplanned water reuse in the *wadis*

With the diminishing contribution of natural springs to the base flow in some *wadis* due to over-pumping of groundwater in the highlands, and the increasing discharge of effluent into *Wadi* Zarqa from urban centres upstream, reclaimed water has become a significant portion of the dry-season flows. Farmers, who have traditional water rights to the base flow, have continued to irrigate from the flow in the *wadi*, that is mostly wastewater effluent. The Ministry of Health, in coordination with local authorities and the WAJ, recognising that the microbiological quality of such water presents a serious health risk and jeopardises wider export markets for crops, has enforced the existing standard (JS893/1995) where possible, but the irrigation of ground-grown vegetable crops persists in the less-accessible areas of *Wadi* Zarqa (McCornick *et al.*, 2001). The rights of the farmers to base flow in these *wadis* is recognised and respected, but only for use on restricted crops. In fact, with increasing populations in the Amman Zarqa area in recent years, flow in the *wadis* has increased and become more reliable, enabling the farmers to use larger volumes of water and irrigate larger tracts of land.

Indirect reuse of wastewater effluent

The majority of the reclaimed water generated in Jordan originates in the Amman Zarqa Basin (see Fig. 14.1). Treated effluent from the As-Samra WWTP is discharged to *Wadi* Zarqa. The *wadi* flows into the King Talal Reservoir (KTR), picking up whatever surface runoff occurs in the Amman Zarqa catchment. The water in the reservoir, blended with water from the King Abdullah Canal, when available, is used for irrigation in the southern portion of the Jordan Valley (McCornick *et al.*, 2002). From a Jordanian legal aspect this water, downstream of the KTR, is no longer considered to be reclaimed water. From a practical perspective, however, the microbiological and chemical qualities of the water are affected by the level of treatment at the WWTP and by non-point sources contaminating surface runoff from the Amman Zarqa catchment.

Motivation to Revise Water Reuse Standards

Policy and strategy context

Since 1998 Jordan has been revising the strategy and policies used to manage its scarce national water resources. The National Water Strategy (MWI, 1997) recognises that population pressure in Jordan has already caused a chronic deficit in available freshwater that has

Table 14.2. Revised standards of water reuse in Jordan (Government of Jordan, 2003).

Purposes of water use	Artificial groundwater replinish-ment	Cooked vege-tables	Recreation grounds, courses and roadsides inside the cities	Golf courses	Fruit trees	Road-sides outside the cities	Open green areas	Cereals and fodder crops	Industrial crops	Forest trees	Discharge into valleys and torrential streams	
											Mechanical system	Natural system
	Operating specifications											
BOD (mg/l)	15		30			200			300		60	120
COD (mg/l)	100		100			500			500		150	300
DO (mg/l)	>2		>2			–			–		>1	>1
TSS (mg/l)	50		50			150			150		100[b]	–
pH (unit)	6–9		6–9			6–9			6-9		6–9	6–9
Cl_2 residual	0.5–1.0		0.5–1.0			–			–		0.5–1.0	–
Turbidity (NTU)[a]	2		10			–			–		–	–
NO_3 (mg/l)	45		45			70			70		45	45
NH_4 (mg/l)	5		10			–			–		–	–
T-N (mg/l)	30		45			45			45		45	45
	Environmental and health specifications											
E. coli MPN or CFU/100 ml	<2.2		100			1000			–		500	1000
Intestinal helminths eggs (egg/l)	≤1		≤1			≤1			≤1		≤1	≤1

[a] NTU: unit that measures turbidity of water using a typhilometer.

[b] Water treatment stations that use mechanical methods and have polishing (settlement) ponds are allowed to exceed twice the times TSS standard.

resulted in over-extraction of groundwater. Opportunities to develop new freshwater sources are limited, and those that exist are expensive, with high operating costs. Given this, treated wastewater is considered to be a resource that, with due care for public health and the environment, should be reclaimed and reused for agriculture and other non-domestic purposes, including groundwater recharge.

The National Wastewater Management Policy (MWI, 1998) states that water reuse for irrigation should be given a high priority, and that reclaimed water is to be sold at prices that, at a minimum, cover the operation and maintenance costs of delivery. The Policy also allows for the Jordanian Standards on Water Reuse to be periodically examined.

Furthermore, the Policy states that any use of reclaimed water must:

- Protect the public
- Conserve resources (water, soils/land, natural vegetation, etc.)
- Comply with international treaties
- Ensure environmentally sound practices.

Proposed uses of reclaimed water

In addition to the present water reuse practices in Jordan, there are a number of proposed developments where water reuse would be beneficial, yet would have been prohibited or difficult to manage under JS893/1995.

A case in point is the existing Aqaba WWTP, located on the coast of the Gulf of Aqaba at the northern extremity of the Red Sea. This WWTP is now operating at capacity, but the fast-developing Aqaba free trade zone will soon increase the treatment capacity requirements considerably. A major reconstruction project is scheduled to be completed in late 2004. The specifications for the new facility call for zero emissions of effluent into the Gulf of Aqaba. This requirement has further motivated decision-makers to maximise the use of reclaimed water. In addition to the relatively successful irrigation of date palms with reclaimed water that complies with the JS893/1995, the intent is to use the reclaimed water to irrigate more date palms, other crops, a golf course, and the urban

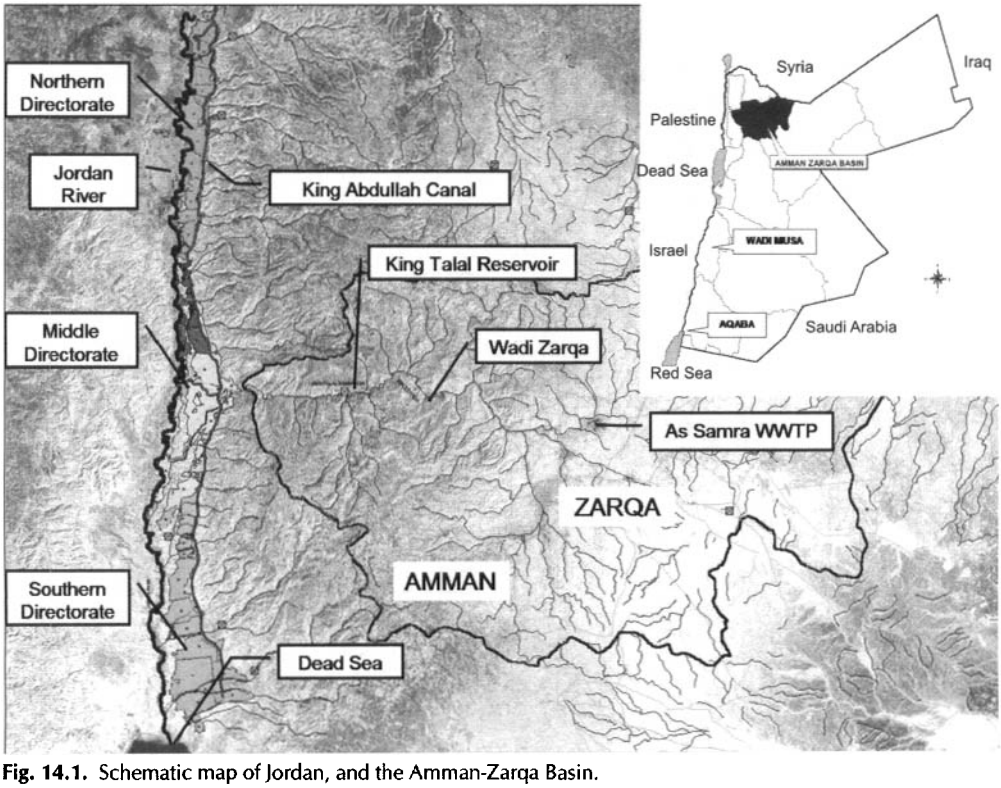

Fig. 14.1. Schematic map of Jordan, and the Amman-Zarqa Basin.

landscape within the Aqaba city area. Furthermore, industry presents a potential additional demand for the reclaimed water. JS893/1995 did not allow for the use of sprinkler systems that are required for the golf course and such use is still not allowed under the new standards.

A major consideration in the use of reclaimed water in Jordan is the potential impact of regulations on the export market of fresh fruit and vegetables, and the possibility of restrictions placed by importing countries based on the poor microbiological quality of the irrigation water.

Other reasons (Sheikh, 2001) for revisiting Jordanian Standard JS893/1995 are:

- Incorporating the latest knowledge about use of reclaimed water
- Incorporating water reuse into the overall integrated management of water resources in Jordan
- Protecting public health in use of reclaimed water – while leaving other important considerations (environmental protection, soil characteristics, agricultural productivity) to the discretion of customers and other governmental entities
- Simplifying compliance with uniform standards for all stakeholders
- Implementing a broad range of water reuse activities ranging from irrigation of crops eaten raw that would require disinfected tertiary effluent, to small community and satellite facilities where the WWTP produces secondary treated effluent
- Streamlining enforcement of the standards.

The Process of Revising the Standards

Technical experts were engaged to work with staff members of various national government agencies [MWI, WAJ, and the Jordan Valley Authority (JVA)] on revision of the Water Reuse Standards. Knowledge of the problems faced by farmers, industry, and GoJ helped to develop an appreciation of the constraints faced by all parties using treated effluent. A three-tiered standard was developed to ameliorate the shortcomings of JS893/1995.

From the expert review of the Jordanian Standards for Treated Wastewater Reuse insight was provided on ways and means of enhancing these Standards and of providing guidelines for water reuse and industrial discharges to sewers. Presentations highlighting experiences of other countries shed light on the benefits of using of reclaimed water. They also addressed and alleviated the concerns of the public, decision-makers and GoJ technical specialists. These informational sessions proved to be highly useful in reaching consensus on the content of the new Standard.

Review of Standards

The review of the Standards began early in 2000 when the history of relevant legislation and standards was reviewed (Nazzal *et al.*, 2000). A detailed review of JS893/1995 was conducted, present practices were examined, and a framework for revising them was developed (Sheikh, 2001). Over this period, input was sought from various stakeholders in the MWI, WAJ, JVA, Ministry of Health, Ministry of Agriculture, and tertiary education institutions.

Proposed framework

A proposed regulatory framework, with the primary goals of protecting public and farmworker health, and developing a credible regulatory system for domestic and export markets, was presented to the stakeholders. The expectation was that, with stakeholder input, revised standards would evolve from the framework, and would eventually be adopted formally.

The proposed framework has three tiers. Tier 1 is legally enforceable water reclamation standards aimed at protecting public and farmworker health (see Table 14.3). This will be accomplished through the regulation of parameters that: 1. ensure optimal performance of the WWTPs, 2. indicate the microbiological safety of reclaimed water, and 3. can be controlled at the WWTPs. Note that under the originally proposed regulatory regime, unrestricted irrigation (last column of Table 14.3) would, unlike JS893/1995, have allowed the irrigation of vegetables eaten raw.

The principles underlying Tier 1 allow for a wide range of uses of reclaimed water. For the

Table 14.3. Proposed Tier 1 standards for Jordanian water reuse regulation[a] (Sheikh, 2001).

Process control parameter	For use in restricted irrigation of		For use in unrestricted irrigation of vegetables eaten raw, public parks, other urban uses
	Orchards, forest, fodder, industrial crops, grains	Vegetables eaten cooked, processed	
Faecal coliform (MPN/100 ml)	1,000	200	23
Nematode eggs (no./l)	1	1	1
BOD5 (mg/l)	100	50	15
Turbidity (NTU)	12	10	2
Total nitrogen (mg/l)	45	45	30
Residual chlorine (mg/l)	NR[b]	NR	0.5

[a] Includes parameters that can be controlled by wastewater treatment operators.
[b] NR = not required.

irrigation of orchards, trees, fodder, industrial crops and grains, the WHO standards are still used as a guiding principle. For areas with a fragile environment, such as those around Aqaba, a higher level of treatment is necessary regardless of water reuse requirements. Tier 1 would have originally allowed for the use of highly treated effluent for irrigation of raw-eaten vegetables and parks with unrestricted public access as well as for other non-potable urban uses.

Tier 2 criteria is a set of guidelines aimed at protecting the soil and maintaining the highest possible level of crop productivity. Unlike the Tier 1 Standards, these guidelines are not legally enforceable. Rather, they are intended to assist the decision on a given use of an available source of reclaimed water. Guideline constituents are relevant to soil and agricultural productivity but are beyond the control of a typical WWTP. If they should not be present in an effluent stream, they are best removed at source. (An excellent example in Jordan was the case of boron in the Amman Zarqa basin, that was successfully reduced to safe levels through a source-control campaign in the 1980s and 1990s). Separating guideline parameters from standard parameters is a major departure from the JS893/1995, that attempted to regulate all parameters. The sampling and monitoring of guideline parameters would not be the responsibility of the independent agency proposed to oversee water reuse, but of other agencies. A list of guideline parameters and their limits is presented in Table 14.4.

Tier 3 is reserved for the so-called constituents of emerging concern, i.e. synthetic organic compounds, disinfection byproducts, pharmaceuticals, and endocrine disruptors. These constituents are not generally of major concern in water reuse, but they can cause problems if they end up in the domestic water supply. The revised standards call for continued research and vigilance in developing information on such constituents.

In addition to numerical standards and guidelines, the proposed regulatory framework includes the following eight narrative sections:

1. Definitions
2. Sources of reclaimed water
3. Uses of reclaimed water
4. Use area requirements
5. Monitoring requirements
6. Reporting and operational requirements
7. Design requirements
8. Reliability requirements.

Framework review

The draft framework was revised and distributed to the stakeholders and key experts in mid-2001. For new water reuse standards to be ratified in Jordan, they must first be agreed upon by the Select Committee of Wastewater Experts of the Water Authority of Jordan; next, they must be approved by the Standards Committee of the Jordan Institute of Standards and Metrology (JISM), and finally, they must receive the approval of the Director General of JISM. Both committees draw experts from government and non-government agencies, and the university community. Several members of these committees had served as key experts

Table 14.4. Upper limits of guideline values for properties of effluent used for irrigation and values of standard specifications in the event effluent water is discharged into valleys and streams or used for groundwater replenishment.

Tested elements (mg/l)[a]	Guideline values for irrigation	Standard specifications[b]
FOG	8	5.0
Phenol	< 0.002	< 0.002
MBAS	100	25
TDS	1,500	1,500
Total PO_4	30	15
Cl	400	350
SO_4	500	300
HCO_3	400	400
Na	230	200
Mg	100	60
Ca	230	200
SAR	6–9	6
Al	5	2
As	0.1	0.05
Be	0.1	0.1
Cu	0.2	0.2
F	1.5	1.5
Fe	5.0	5.0
Li	2.5 (0.075 for citrus crop)	2.5
Mn	0.2	0.2
Mo	0.01	0.01
Ni	0.2	0.2
Pb	5	0.2
Se	0.05	0.05
Cd	0.01	0.01
Zn	5	5
Cr	0.1	0.02
Hg	0.002	0.002
V	0.1	0.1
Co	0.05	0.05
B	1.0	1.0

[a] For explanation see Table 14.1

[b] Standard specifications should be adhered to when discharging effluent water into valleys or steams, or when using it for used for groundwater replenishment.

and stakeholders in the development of the framework.

In early 2002, a series of workshops was held at different locations in Jordan with the two committees and other stakeholders, including those interested in the proposed wastewater and water reuse facility at Aqaba. These workshops, using the draft framework as a guide, sought to develop a rational revision of the water reuse standards. Through a process of active negotiation amongst the various stakeholders, the workshops led to consensus on the following:

- Separation of the water reuse standards from the environmental discharge standards
- Division of the existing list of constituents into separate standards and guidelines for water reuse, and agreement on the appropriate numerical level for each
- Allowance for use of a highly treated reclaimed water for irrigation of crops eaten raw and other urban uses
- Allowance for groundwater recharge with reclaimed water, with the understanding that each proposed application is to be studied thoroughly, on a case-by-case basis
- Allowance for the use of sprinkler application systems using tertiary disinfected reclaimed water
- Creation of an independent and impartial enforcement body for oversight of water reuse activities and effective enforcement of adopted standards
- Publication of the operation and maintenance records, and monitoring of results from the treatment facilities.

Finalising the Standards and Guidelines

The workshops resulted in consensus, at least among the stakeholders present, on a revised listing of constituents, a distinction as to whether each constituent was a standards or guideline constituent, and suggested numerical values for each. Consensus was also reached on revising the existing standards to incorporate the major points of agreement presented above.

Subsequently, as the draft standards and guidelines progressed through the formal review process, further changes were made. The new standards are in two tiers (Standards and Guidelines). A major change from the proposed standard is that the irrigation of vegetables eaten raw with reclaimed water, no matter how well it is treated, is to remain prohibited. Recharge of groundwater is permitted, but not for aquifers that are to be used for drinking water supplies.

The application of reclaimed water by sprinkler irrigation remains prohibited. The

new standard has been approved by the JISM, and was enacted in 2003 under the title JS893/2003.

Conclusions

Prior to implementation of direct water reuse, the GoJ, with the support of USAID, revisited and revised the existing Jordan Water Reuse Standard (JS893/1995). The review and revision process was informed by senior international expertise in the water reuse standards field, government agencies, and senior technical specialists from government and non-governmental organisations. Knowledge of the problems faced by farmers, and the industry, and the GoJ helped in the development of an appreciation of the constraints faced by all parties with regard to the reuse of treated effluent.

A detailed review of the existing Jordanian standards for water reuse provided insight into the ways and means of enhancing the standards and providing guidelines for water reuse and industrial discharges to sewers. A three-tiered framework of standards/guidelines was used to guide the process.

Presentations, workshops and study tours highlighting experiences of other countries shed light on the benefits of the use of properly treated wastewater and addressed and alleviated the concerns that the public, decision-makers and technical GoJ specialists had with regards to the water reuse issue.

The review and revision process proved to be highly beneficial in bringing differing opinions to close agreement on the content of the standard. The standards have now been approved by the JISM and officially enacted . It is expected that the new standards will provide Jordanian farmers with opportunities to comply without losing any vested rights to riparian water, and with much improved health and safety conditions for themselves, their children, and their customers.

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15 Treated Wastewater Use in Tunisia: Lessons Learned and the Road Ahead

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Abstract

With per capita freshwater availability of around 450 m^3, Tunisia is one of the most drought-stressed countries in the Middle East and North Africa (MENA) region. In the MENA region, and indeed worldwide, Tunisia along with Israel, has been recognised as a leader in the area of wastewater reclamation and use. This chapter presents the case of a middle-income country that has pursued a conscious strategy of treated wastewater reuse in agriculture with a fair measure of success. The current status of wastewater treatment and the use of treated wastewater in agricultural irrigation are reviewed. The impacts of water quality are discussed in this context, and the institutional, legal, and economic aspects analysed. The final section presents the lessons learned from the Tunisian experience and the options and hurdles for expanding the scope of treated wastewater use in agriculture. The key findings are that despite strong government support, treated wastewater use in irrigation has faced several constraints, chief among them being problems of social acceptance, agronomic considerations and sanitation, and restrictive regulations that have tended to limit its full potential for development. Further, the multiplicity of agencies and overlapping institutional responsibilities have also tended to limit the potential for expansion. Through its carefully phased approach to treated wastewater use and the concomitant development of a regulatory framework that prohibits untreated wastewater use, Tunisia has significantly mitigated the environmental and public health risks associated with untreated wastewater use elsewhere in the world.

Background

Tunisia is a middle-income country located on the southern rim of the Mediterranean Sea with a population of approximately 10 million that is growing at about 1.8% per annum. Annual per capita income is around US$4,250 (World Development Report, 2002). Tunisia has a semi-arid climate and few renewable natural resources. It occupies 165,000 km^2 with the Atlas mountain range in the north accounting for 25% of the area. The Central Steppe and Sahel regions make up another 25% and the Southern Sahara region 50%. The annual rainfall varies from 600 mm in the north (400 mm in Tunis) to 100 mm in the southern region. The population is relatively urbanised, with 58% living in urban areas on the northern and eastern coast. Administratively, Tunisia is divided into 23 governorates, 136 counties, and 250 communes.

 Wastewater Use in Irrigated Agriculture
(eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

Water Resources and Quality

The annual total volume of exploitable water resources in Tunisia is about 4670 million cubic metres (MCM) of which about 57% (2,700 MCM) is surface water and the remaining 43% (1970 MCM) groundwater. Tunisia is a drought-stressed country with per capita renewable water availability of 486 m^3 – well below the average of 1,200 m^3/capita for the Middle East and North Africa (MENA) region. Of the available surface water resources of 2,100 MCM, only about 1,220 MCM are expected to be captured for actual use. Eighteen existing dams, 21 projected dams, and 235 hillside dams are expected to augment the available supply but rapid sedimentation of reservoirs will progressively reduce storage capacity and shorten life. Deep groundwater extraction rates are currently at 73% of annual recharge, and shallow groundwater is at 97% in the coastal and central regions. Excessive groundwater extraction in the coastal regions of Cap Bon, Soukra, and Ariana has resulted in saline intrusion in many areas leading to groundwater being rendered unsuitable for further irrigation. Water quality, especially salinity, is a serious constraint. Only 50% of all water resources have salinity levels lower than 1,500 mg/l and can be used without restrictions. While the surface water has a generally low salinity (with the exception of the tributaries entering the Medjerda river from the south), groundwater resources are badly affected with 84% of all groundwater resources having salinity levels of more than 1,500 mg/l and 30% of the shallow aquifers more than 4,000 mg/l. World Health Organization (WHO) *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture* (1989) specifies considerably lower limits for potable water. This saline irrigation water reduces crop yields and requires the installation of costly drainage systems to maintain soil fertility. The effect of salinity on the water balances is an important consideration for Tunisia's water resource planning (World Bank, 1994). As in most other countries, agriculture accounts for the bulk of water consumption (89%) with domestic use accounting for 8% and industrial use 3%.

Tunisia has also experienced three serious droughts in the last decade that have affected agricultural growth and domestic consumption. With an increasing population, rapid urbanisation, and rise in living standards developing additional water resources is imperative. The last three Five-Year Plans (Government of Tunisia, 1987, 1992, 2002) have emphasised water harvesting and treated wastewater use. Since the severe drought in 1989, the use of treated wastewater in irrigation has been a part of the Government's overall water resource management strategy. As seen in Table 15.1, treated wastewater use and desalination are both expected to virtually double in the coming years.

Current Status of Wastewater Treatment

About 70% of the urban population is connected to a sewerage network but among the rural population only 20% are connected. The number of wastewater treatment plants (WWTPs) has gradually risen in the last decade and is expected to reach 83 by 2006 (Table 15.2). Currently, 61 WWTPs are in operation with

Table 15.1. Projected water resources in Tunisia – accessible (A) and available (B) (MCM/annum) for different time horizons (1998).

	1996		2010		2020		2030	
	A	B	A	B	A	B	A	B
Large dams	1,340	871	1,800	1,170	1,750	1,138	1,750	1,138
Hillside dams and lakes	65	59	100	50	70	35	50	45
Tubewells and springs	997	997	1,250	1,150	1,250	1,000	1,250	1,000
Open wells	720	720	720	720	720	620	720	550
Treated wastewater	120	120	200	200	290	290	340	340
Desalinated water	7	7	10	10	24	24	49	49
Total	3,249	2,774	4,080	3,300	4,104	3,107	4,159	3,122

Source: Bahri, 2000.

9,650 km of wastewater network collecting 178 MCM wastewater, 148 MCM of which are treated and used in agriculture, to water golf courses and for other purposes. Almost 83% is treated in 44 WWTPs by activated sludge, 0.5% is treated in 3 WWTPs by biological filters, 7.6% in 7 plants in natural lagoons, and 8.6% in 7 plants in aerated lagoons (Koundi, 2001). Effluent is treated to the primary and secondary levels.

Table 15.2. Evolution in number of wastewater treatment plants in Tunisia, 1995–2006.

Year	WWTPs (number)	Capacity (MCM/ annum)	Treated (MCM/ annum)
1995	48	135	111
1996	49	137	116
1997	51	145	131
2001	66	175	155
2006	83	185	165

Source: Ministry of Agriculture, 1998.

Treated Wastewater Use in Agriculture

Tunisia has had a cautious and gradual approach to applying treated wastewater in irrigation. Since 1965, wastewater from the Charguia WWTP has been used to irrigate citrus orchards in the Soukra irrigation scheme covering 1,200 ha (now reduced to 600 ha due to urbanisation) north of Tunis in order to safeguard them from saline intrusion caused by the overexploited aquifer. However, it was not until 28 July 1989 with the passage of the Decree 89-1047 setting conditions for the use of treated wastewater for agricultural purposes, that the use of treated wastewater in irrigation really expanded in a controlled manner (Ministry of Agriculture, 1998). This Decree set the conditions for the use of treated wastewater in agriculture. In addition to the institutional aspects, the Decree also specified the modalities for control of quality including the necessary physico-chemical parameters, microbiological parameters and the frequency of monitoring (Ministry of Agriculture, 1998). The main legal framework is also contained in the Code des Eaux (Water Code) dating back to 1975. As Table 15.3 shows, use in irrigation and golf courses is predominant. However, only about 35 MCM of treated wastewater is currently used on about 6,500 ha mainly (55%) in the area surrounding Tunis which represents about 20–30% of the volume produced. It is estimated that by 2020 about 20,000–30,000 ha, or about 7–10% of total irrigated area, will be irrigable using treated wastewater (World Bank, 1997; Ministry of Agriculture, 1998).

Table 15.3. Categories of treated wastewater use in Tunisia.

Use	Area irrigated ha	%	Volume used MCM	%
Irrigated perimeters	6,272	90	3.72	43
Golf courses	570	8	4.07	46
Others	155	2	0.95	11
Total	6,997	100	8.74	100

Source: Ministry of Agriculture, 1998.

Effluent Water Quality and Impacts of Treated Wastewater Use

In Tunisia the quality of treated wastewater varies spatially with the lowest salinity found in the northwest (min. 1,000; max. 1,500; average 1,300 mg/l) owing to the good quality of surface water resources and the low level of industrial activity in that region. By contrast, the WWTPs in the south exhibit alarmingly high concentrations of salt due to the salinity of the distribution waters and the presence of important industries that dispose of their wastes in certain stations (min. 2,700; max. 8,900; avg. 4,100 mg/l) (see Table 15.4). This is a major problem for the farmers who express concerns about the long-term impacts on their soils and crops. Around Moknine, the high salinity of the treated wastewater supplied by the National Sanitation Agency [Office National d' Assainissement] (ONAS) resulted in serious soil degradation. In order to drain the salts from the soil and to provide compensation, the farmers in that area now receive free conventional water from the neighbouring

Table 15.4. Average quality of treated wastewater in different regions of Tunisia, 1996.

Region	WWTPs	Mean annual conductivity EC (μS/cm)	Mean annual salinity (mg/l)	Average volume treated (MCM/annum)
Tunis	4	4,877	3,700	5.00
Northwest	4	1,698	1,300	4.77
Northeast	10	2,855	2,200	2.30
Centre	17	4,230	3,300	1.95
South	14	5,253	4,100	1.87

Source: Calculated from Ministry of Agriculture, 1998.

Nebhana dam. A high rate of suspended solids exceeding the norm of 30 mg/l in many cases has also been reported, with associated discoloration of the water. This has also led to complaints about clogging local irrigation systems, and poses a constraint to farmers adopting drip irrigation.

Evidence of microbial contamination exists and poses a health and sanitary risk to both farmers and consumers. A 1985 study jointly carried out by the Ministries of Agriculture and Public Health evaluated the impact of treated wastewater on crops and human health in the Soukra, Borj Touil, and Djebel Ammar areas. The study revealed 141 cases of gastrointestinal (GI) disease (21% of the surveyed Soukra population). Some of the diseases could be related to treated wastewater use, but the study was not exhaustive enough to clearly identify the sources. In 1990, a study carried out by the regional health and agricultural authorities of Ariana in Borj Touil recommended strict control of wastewater use in the Soukra and Borj Touil regions (UNDP *et al.*, 1992). An ONAS survey carried out in 1992 pointed to a lack of information amongst farmers about wastewater quality, health risks related to wastewater use and impacts on crops and soils. Farmers do not systematically receive health education concerning the risks they incur, nor do they adopt the preventive measures that are advocated by the public health service. The Ministry of Public Health does not have the necessary means or organisation to effectively supervise the use of treated wastewater in irrigation. Implementation of effective disinfection for reclaimed wastewater effluents using maturation ponds or high-rate ponds could reduce the public health risks. This would also eliminate the need for extensive and complex epidemiological studies to assess the health status of populations using treated wastewater for irrigation or living within the irrigated areas (Asano and Mujeriego, 1992).

Water Quality Standards and the Legal Framework

Treated wastewater use in agriculture is regulated by the 1975 Water Code and associated Decree No. 89-1047 (Ministry of Justice and Human Rights, Republic of Tunisia, 1989). The Water Code prohibits use of untreated wastewater in agriculture and restricts the use of reclaimed water for irrigation of any vegetable to be eaten raw. The use of secondary treated effluents for growing all types of crops except vegetables, whether eaten raw or cooked is allowed. Water quality criteria for treated wastewater use in agriculture have been developed using the 1989 WHO Guidelines as the basis and a list of crops that can be irrigated has also been established. According to the 1989 Decree No. 89–1047, treated effluent can only be used to irrigate crops that are not directly consumable. No vegetables can be irrigated with treated wastewater. The main crops irrigated with treated wastewater are: fruit trees including citrus, grapes, olives, peaches, pears, apples, pomegranates, etc. (28.5% by area); fodder including alfalfa, sorghum, clover, etc. (45.3%); industrial crops such as sugarbeet (3.8%); and cereals (22.4%). 57% of the area equipped with irrigation facilities is sprinkler-irrigated and 48% surface irrigated. Water quality standards have also been established for wastewater

disposal in receiving waters (seas, lakes and rivers). According to Bahri (2000), monitoring the quality of treated water for a set of physical-chemical parameters once a month, for trace elements once every 6 months, and for helminth eggs every 2 weeks was originally envisaged. However, due to organisational and capacity constraints in the Ministry of Public Health, such monitoring is not systematic. Nonetheless, unlike other countries of the Middle East (e.g. Syria and Egypt), there is no evidence of the widespread use of untreated wastewater in agriculture. Compliance with existing restrictions on cropping patterns is relatively good. This is facilitated by the fact that the bulk of the wastewater (over 50%) originates in the capital Tunis, which is relatively small (population approximately 1 million) allowing the effective enforcement of existing guidelines. In small and medium-sized towns, ONAS is currently developing an indigenous low-cost technology for treatment but coordination with the new Ministry of Agriculture, Environment, and Water Resources, that was formed in 2002 when the Ministries of Agriculture and Environment merged, to determine market demand from farmers is still limited.

Economic and financial aspects of wastewater treatment

ONAS, which is responsible for the collection, treatment, and the disposal of wastewater, faces varying costs of treatment depending on the age and type of the plant, its location, and capacity with a high of US$0.51/m^3 (Menzel Bouzelfa WWTP in the northeast; 1995; capacity 2065 m^3/day) to a low of US$0.02/m^3 (Dar Jerba WWTP in the south; 1972; capacity 1100 m^3/day). These costs include the investment,[1] and operations and maintenance (O&M) costs. The average cost of secondary treatment is estimated at US$0.14/m^3 but a study commissioned by ONAS in 1996 estimates that this will more than double to US$0.29/m^3 in the next 5 years or so, owing to the high costs of new investments (Ministry of Agriculture, 1998).

In Tunisia, the price charged by the Commissariat Régional du Développement Agricole (CRDA), the Regional Commissioner for Agricultural Development, for the water supplied for irrigation (conventional and treated wastewater) varies by governorate. Usually the price of water includes the costs of conveyance, O&M, but not of investment. In the northern CRDA of Ariana, generalised irrigation costs are determined by the overall price of O&M, irrespective of whether the specific source is treated wastewater. In 1996, this was estimated at 103 millièmes (mmes)/m^3 ~US$0.06/m^3 (1 Tunisian Dinar (DT) = 1,000 millièmes; 1 DT = US$0.66).

In the Ben Arous CRDA, the O&M costs of treated wastewater were estimated at 122 mmes/m^3 including labour costs (18%), costs of electricity for pumping (68%), and other costs (14%). The estimation of the O&M costs is sensitive to the volume of water pumped and billed. For example, in the Ariana CRDA, the quantity of water pumped in the irrigation perimeter was more than 2.9 MCM. If this volume was in reality properly accounted for, the O&M costs would have been 44 mmes/m^3, lower than those actually charged by the CRDA, i.e. 55 mmes/m^3. Table 15.5 presents the variation in treated wastewater prices among CRDAs and the differences between the prices charged for treated wastewater and conventional water (Ministry of Agriculture, 1998).

In 1997, a Presidential Decree set the price of treated wastewater at a uniform 20 mmes/m^3 or US$0.01/m^3 in order to encourage farmers to expand its use. This is a significant subsidy considering the average cost of treated wastewater is estimated at US$0.14/m^3, and is expected to rise to US$0.29/m^3 in the coming years as new WWTPs come on line. However, the impact of this subsidy in expanding demand has been far lower than expected due to such reasons as poor quality, social acceptance, agronomic considerations, and sanitation. Further, despite the tariff reforms undertaken by the Government, which require the CRDAs to annually raise the price of water by 15% on average, the price of conventional water still remains very low. Where the farmers have a choice between treated wastewater and

[1] Capital costs amortised over 45 years with an interest rate of 7%; equipment amortised over 15 years at 7%.

Table 15.5. Comparison of prices [DT/m³ (US$/m³)] for treated wastewater and conventional water in Tunisia prior to the 1997 Government Decree.

WWTP (name)	Irrigation scheme	Price of wastewater charged by CRDA	Price of conventional water	Price of wastewater as a percentage of conventional water (%)
Cherguia	Borj Touil	0.031 (0.020)	0.091 (0.060)	34.1
Choutrana	Soukra	0.069 (0.046)	0.091 (0.060)	75.8
Sud Méliane	Mornag	0.059 (0.039)	0.090 (0.059)	65.6
SE3 Nabeul	Bir Faiedh, Oued Souhil	0.059 (0.039)	0.062 (0.041)	95.2
SE4 Nabeul	Borj Khiar-Mess. Borj Romana	0.059 (0.039)	0.062 (0.041)	95.2
Sousse south	Zaouiet Sousse	0.050 (0.033)	0.104 (0.069)	48.1
Kairouan	Draa Tammar	0.032 (0.021)	0.061 (0.040)	52.5
Sfax	Hajeb	0.020 (0.013)	0.030 (0.020)	66.7

Source: Calculated from Ministry of Agriculture, 1998
Note: 1 DT = US$0.66

conventional water, they prefer conventional water because of the crop restrictions on treated wastewater and problems with its quality. For farmers who would not otherwise have had access to irrigation, treated wastewater is the preferred option because it has helped raise their incomes. For example, farmers living on the perimeter of Borj Touil on the northern coast had no access to surface water resources, and groundwater resources there are far too saline for their use

Institutional and Organisational Structure

Water resources are managed at the national level by the newly-consolidated Ministry of Agriculture, Environment and Water Resources (MAEW) formed by the merger of the Ministry of Environment with the Ministry of Agriculture in September 2002. Its hydraulic works section, the Direction Générale des Grands Barrages et des Grands Travaux Hydrauliques (DGBGTH), is responsible for the construction of major water resources projects. Responsibility for the water supply systems in urban areas and large rural centres is assigned to the Société Nationale d'Exploitation et de Distribution des Eaux (SONEDE), a national water supply authority that is an autonomous public entity under the MAEW. Planning, design, and supervision of small and medium water supplies and irrigation works are the responsibility of the Direction Générale du Génie Rurale (DGGR), a department of the MAEW. Responsibilities for managing investment planning and implementation of projects and agriculture activities are with the Commissariats Régionaux au Développement Agricole (CRDAs). These were created as semi-autonomous agencies in each of the country's governorates to represent the Ministry of Agriculture, now the MAEW. They now manage over 50% of public investment in the agriculture sector. A few water users groups (Associations d'Intérêt Collectifs, AICs) have also been created to handle water distribution e.g. the AIC in Monastir. In 1975, with the assistance of the World Bank, the Government created the ONAS, which is responsible for the sewerage subsector management including the collection, treatment, and disposal of wastewater in urban, industrial, and tourism zones. In 1993, ONAS's mandate was consolidated under the (then) created Ministry of Environment and Land Use Planning with increased responsibility for sewerage operations. Now ONAS has expanded into an institution responsible for the protection of the aquatic environment, working in close cooperation with the National Environmental Protection Agency (Agence Nationale de Protection de l'Environnement, ANPE, established in 1989), which is charged with developing and enforcing regulations concerning wastewater discharge. The

other key ministry involved is the Ministry of Public Health (MPH), which regulates the quality of wastewater used for irrigation and of marketed crops, as well as monitoring water pollution and enforcing control. This Ministry has an important say in pollution control and wastewater use regulations.

Lessons Learned and the Road Ahead

The results and experience gained in Tunisia on treated wastewater use place Tunisia among the leading countries in the Mediterranean area in the field of treated wastewater use in irrigation. It is one of the few countries where treated wastewater use has been made an integral part of environmental pollution control and water management strategies. The knowledge and experience gained by researchers in the Institut National de Recherche Génie Rural, Eaux, et Forêts (INRGREF) should provide excellent guidance to other countries in arid and semi-arid regions in defining the different irrigation uses for reclaimed wastewater, quality requirements for specific uses, the treatment levels best suited to each use, and the most adequate management options available for implementing current and proposed projects. Through its planned and cautious approach together with a well-developed regulatory framework, Tunisia has significantly mitigated the environmental and public health risks associated with untreated wastewater use elsewhere in the world. As a middle-income country, Tunisia also has the benefit of an affluent, well-educated population that has helped to practically eliminate untreated wastewater use. This has not meant that wastewater use in Tunisia is without its constraints. The following important lessons have been learned from Tunisia's implementation of a conscious strategy of treated wastewater use over the decades.

Institutional

There is a multiplicity of agencies that are currently involved in treated wastewater use with often conflicting objectives and overlapping responsibilities. The lack of co-ordination has resulted in a mismatch in the supply and demand. ONAS generates treated wastewater according to its prerogatives and the established quality standards, but not necessarily to match the quality and quantity demands of the primary users – the farmers. On the other hand, the CRDAs representing farmers' interests would like to obtain treated wastewater as needed during the cropping season at certain times, in certain volumes, and of a quality appropriate for crops

Currently there is no single agency with responsibility for treated wastewater reuse (regulation and enforcement of standards and procedures, management, etc.). A possibility for increased coordination among different stakeholders would be the creation of an executive commission with representatives from the key ministries and agencies. This commission would be tasked with implementing the national strategy for treated wastewater use including supervision, coordination, control and establishment of new use initiatives, education programmes etc. Due to Government concerns about rising public expenditures in the civil services, implementation of this recommendation in the near future is unlikely, unless the wastewater commission were to be created by drawing from the staff of existing agencies.

Technical

Firstly, in order to be able to better match demand and supply, the development of associated infrastructure especially inter-seasonal storage facilities needs to be emphasised. Farmers are willing to pay more if they can be assured of a timely and reliable quantity and quality of water supply. With the growth in the number of WWTPs, ONAS has to work with MAEW, CRDAs, and farmer representatives to determine technical and management solutions that are mutually satisfactory. Secondly, with the Government's push towards water-saving technologies on a national scale, effective filtration systems need to be devised to enable the use of treated wastewater in micro-irrigation systems such as drip irrigation without clogging.

Social/agronomic

Farmers are still reluctant to use treated wastewater and do not possess the necessary training to use it for agricultural irrigation in a safe and hygienic manner. For the farmers who do use treated wastewater, there is little evidence to suggest that chemical fertiliser use has decreased, a process that is likely to result in over-fertilisation and aquifer contamination in the long term. This points to the need to strengthen agriculture and irrigation extension services so that farmers are appropriately trained. Extension agents themselves need to be better equipped to respond to farmers' needs and concerns.

Public outreach and education programmes are also essential if greater social acceptance of treated wastewater is to be generated. The use of treated wastewater effluents is legitimate from the Islamic religious viewpoint, and has therefore to be examined in each case from the aspects of health, cost, and public acceptance (Farooq and Ansari, 1983; Faruqui *et al.*, 2001). Building community participation through water users groups (AICs) during the planning stages of projects can help build socio-cultural acceptance.

Economic

The current standards and restrictions on cropping patterns will need to be revisited. Current restrictions on the use of treated wastewater for higher-value crops discourage farmers from using this resource despite its highly subsidised price. This will necessitate a revision in the 1975 Water Code and the associated regulatory decrees. The Government is already thinking along these lines and will develop a revision of the Water Code that will result in a more practical pricing structure and a revision of the cropping restrictions based on the quality of treated wastewater. The Government's emphasis on treated wastewater use in irrigation has not been based on a rigorous market assessment of real demand. Too often, the rates of return on wastewater treatment and reuse projects are artificially high because they assume a rate of use that is unrealistic. There is untapped demand for industrial and recreational use of treated wastewater. Implementation of a market-based strategy of treated wastewater use will necessitate greater coordination between the different stakeholders. The absence of a single coordinating agency will be a major hurdle.

Endnote: At the time of writing, the author was a Visiting Scientist at the South Asia Regional Office of the International Water Management Institute (IWMI) in Patancheru, India and Senior Economist in the Rural Development, Water and Environment Department, Middle East and North Africa Region of the World Bank.

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16 Confronting the Realities of Wastewater Use in Irrigated Agriculture: Lessons Learned and Recommendations

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Abstract

This concluding chapter synthesises results and lessons learned throughout this volume, which deals with the reality of wastewater use in agriculture in developing countries. It then extrapolates from these lessons, to make pragmatic recommendations aimed at protecting both the public health and farmers' livelihoods. Addressing these lessons in a significant fashion is becoming ever more necessary, as it is likely that wastewater use will increase in many less-developed countries, due to growing urban and peri-urban populations and their matching demands for produce. The practice also deserves recognition for its potential socio-economic benefits, since some farmers would be unable to earn a living without using wastewater, and for others, its use increases the income they would normally make, lifting them out of poverty. However, unregulated wastewater use also raises serious concerns about the health of both consumers and farmers, creating the competing need to balance health impacts against livelihood needs. This chapter elucidates lessons learned, and makes four recommendations to policy-makers and practitioners: 1. to develop and apply appropriate guidelines for wastewater use, 2. to treat wastewater and control pollution at source, 3. to apply a range of non-treatment management options, and 4. to conduct research to both improve understanding of the practice, and to identify opportunities and constraints to the adoption of these recommendations.

Introduction

This book set out to describe the reality of wastewater use in agriculture in developing countries, and to make pragmatic recommendations aimed at protecting both the public health and farmers' incomes. The thematic chapters explored a number of issues that are necessary to understand the different dimensions of the problem, including a suggested classification of the different types of wastewater use, the need to take a livelihood-based approach focused on farmers, the need for public health guidelines, and an analysis of the cost-effectiveness of treatment required to meet guidelines. The case studies demonstrated the wide range of wastewater use practices around the world, and illustrated the futility of prescribing a single, rigid management approach. They also revealed

 Wastewater Use in Irrigated Agriculture
(eds C.A. Scott, N.I. Faruqui and L. Raschid-Sally)

common obstacles to improving the practice, and from these it has been possible to identify key issues that must be addressed in order to maximise the potential benefits, while minimising the potential costs that wastewater use offers.

This concluding chapter now summarises these lessons learned, makes recommendations, and points to future research needs, that could contribute to safe and sustainable wastewater use under the diverse conditions that we have seen.

Extent

The first lesson forms the fundamental basis from which we must proceed, and it is that the general lack of knowledge of the importance of wastewater use impedes its inclusion as a priority issue to be considered in policy-making. Case studies from this volume illustrate this aspect and it is estimated that up to one-tenth of the world's population eats food produced using wastewater (Lunven, 1992). As popula-

Lessons Learned

The complex challenges of managing wastewater require a pragmatic, proactive and forward-looking perspective. The lessons learned from past experience with wastewater use and management suggest that:

- Comprehensive realisation of the importance of wastewater use in agriculture is still on the peripheral edges of public awareness, and is not always clear to many policy-makers and donors;
- There is insufficient understanding of the social and economic factors that drive farmers to use wastewater, and thus inadequate consideration of these in policy formulation;
- The protection of public health and the alleviation of poverty are not mutually exclusive outcomes when it comes to wastewater use, however, one may have to be given greater emphasis than the other in different contexts;
- Effective measures do exist to protect health and environmental quality, particularly when these are included in integrated, multi-barrier approaches to wastewater management;
- Rigid wastewater use guidelines tend to become targets rather than norms;
- Effective, lower-cost, decentralised treatment systems exist; conventional, northern treatment technologies tend to be unsustainable, in part because of high capital and recurring costs;
- Many forms of wastewater use are practised in various contexts for different reasons, and individual socioeconomic contexts contribute to varying levels of acceptability of wastewater use;
- Increasing year-round demand for fresh fruits and vegetables in developed countries, and increasing tourism in a globalised world, make wastewater use an issue for more than just developing countries;
- Sound legal and regulatory frameworks require sustained application and enforcement;
- Insecure land tenure mitigates against farmer investment in safer and more efficient wastewater irrigation technologies;
- The informal nature of wastewater irrigation tends to leave it in institutional no-man's land; and
- A lack of coordination among institutions within and outside of government, and the tendency towards isolated, uni-disciplinary research on wastewater, has inhibited the testing and design of integrated, workable solutions.

A successful approach to wastewater management that incorporates these lessons may be incremental if necessary, i.e. building and sustaining individual components, but above all it must be sustained institutionally over the long term. The following sections provide more details on the lessons learned.

tions continue to grow and more freshwater is diverted to cities for domestic use – 70% of which later returns as wastewater – the use of wastewater is certain to increase, both in terms of the areas irrigated, and in the volumes applied. For instance, as outlined by Huibers *et al.* (Chapter 12, this volume), the amount of wastewater used in and around Cochabamba, Bolivia, is expected to double over the next twenty years.

However, the quality of the wastewater used and the nature of its use can vary enormously, both between and within countries. In many low-income countries in Africa, Asia, and Latin America, the wastewater tends to be used untreated, while in middle-income countries such as Tunisia and Jordan, treated wastewater is used. These disparities render direct case comparisons difficult, and even estimating the extent of the practice within countries is problematic – global figures even more so. Here, van der Hoek's suggested classifications, in Chapter 2 of this volume, of the different types of wastewater use – direct, indirect, treated, untreated, planned, and unplanned – will be very useful in comparing different cases, and in developing more meaningful and accurate estimates.

Scenarios of Use

Local socioeconomic conditions and culture are also factors that influence the choice of crops that farmers irrigate, and this has further divergent health impacts. For instance, most vegetables irrigated with wastewater in Pakistan are eaten cooked, whereas in Dakar (Faruqui *et al.*, Chapter 10, this volume), most are normally eaten raw. Additionally, the rationale for using wastewater varies enormously in different contexts. In Tunisia or Jordan, many farmers would be unable to earn a livelihood without using wastewater – they have no other choice. In other cases, for example, in Vietnam (Raschid-Sally *et al.*, Chapter 7, this volume), two different scenarios can occur – in some cases, farmers may inadvertently use wastewater even when they do have an adequate supply of water, because of unplanned discharges into natural water courses and canals, while in others, wastewater may be deliberately pumped into irrigation canals by authorities, when there is inadequate water at the tail-end of irrigation schemes.

Livelihoods and Profitability

In contrast, in situations such as Dakar and Pakistan, farmers prefer wastewater even when freshwater is available, because they earn higher profits using wastewater. As both cases demonstrate, wastewater can be a more reliable source, both in terms of availability and volume, than either rain or freshwater supply from irrigation systems. In these cases, it also allows them to crop more than once a year, sometimes up to 3 crops per year, depending on the crop. In Pakistan (Ensink *et al.*, Chapter 8, this volume), farmers using wastewater earned approximately US$300 per year more than those using freshwater. Furthermore, in addition to generating income for farmers, wastewater use in urban and peri-urban agriculture also provides jobs and income for merchants who sell the produce. In Ghana, it is estimated that using only 10% of the wastewater in urban and peri-urban agriculture (UPA) could generate employment for up to 25,000 farmers, worth US$18 million per year (Sam Agodzo, personal communication).

Given that farmers can earn higher profits by using wastewater, it is becoming increasingly evident that they are also willing to pay for it. In Pakistan, the rent for land with access to wastewater can be two to six times more expensive than for land without such access. For example, in Quetta, which depends on a fossil aquifer projected to run out within 20 years (OCHA IRIN, 2002), the average rent for land with access to wastewater is US$940/ha, compared to US$170/ha for land irrigated with freshwater (Ensink *et al.*, Chapter 8, this volume). In Jordan, the Aqaba wastewater plant is a viable enterprise. Reclaimed water is sold at prices that cover the operation and maintenance costs of delivery, and farmers growing date palms using effluent from the plant continue to renew their contracts (McCornick *et al.*, Chapter 14, this volume).

Environmental Impacts and Health Risks

However, the current practice of wastewater use threatens public health and the environment, and possibly limits its long-term sustainability. The major threat to farmers and their families is from intestinal parasites – most often worms. In Pakistan, farmers using raw wastewater are five times more likely than those using canal water to be infected by hookworms. Living in the small intestine, hookworms cause heavy blood losses, and anaemia and retardation in children (Ensink *et al.*, Chapter 8, this volume). In Dakar, 60% of the farmers using raw wastewater were infected with either amoebae, which cause amoebic dysentery, roundworms, which cause ascariasis, whipworm, or threadworms. The farmers who used a combination of wastewater and groundwater had a lower infection rate of 40%. (Faruqui *et al.*, Chapter 10, this volume). Another health threat is bacterial and viral infections, both minor and serious, which can occur after the consumption of raw vegetables contaminated with faecal matter – the cause of the 1970 cholera epidemic in Jerusalem (Fattal *et al.*, Chapter 5, this volume) and typhoid epidemics in Santiago (1983) (Fattal *et al.*, Chapter 5, this volume), and Dakar (1987) (Faruqui *et al.*, Chapter 10, this volume), were all isolated to urban and peri-urban agriculture (UPA). As Buechler points out in Chapter 3, this volume, health risks also vary according to gender, class, and ethnicity. For instance, women often perform the tasks requiring the most extensive contact with wastewater, such as transplanting and weeding in flooded areas like paddy fields, in both Latin America and South Asia. Furthermore, the children of farmers or farm workers, who have not yet built up immunity, tend to be most at risk to gastrointestinal problems.

In terms of environmental impact, wastewater use over a long period of time can result in heavy metal accumulation, especially with industrial wastewater sources. Irrigation with industrial wastewater has been associated with a 36% increase in enlarged livers and 100% increases in both cancer and congenital malformation rates in China, compared to control areas where industrial water was not used for irrigation (Yuan, 1993, cited in Carr *et al.*, Chapter 4, this volume). In Japan, chronic cadmium poisoning as a result of wastewater use has caused Itai-itai disease, a bone and kidney disorder (WHO, 1992). Ironically, in some of the cases, including Haroonabad, Pakistan, and Dakar, Senegal, groundwater contamination from microbial pathogens or nitrates is not a concern, because the groundwater is already too polluted or saline to serve as a drinking water supply.

Finally, the long-term use of wastewater can become self-limiting due to soil damage. Although the organic matter in wastewater can help improve soil texture and water-holding capacity, wastewater also has harmful effects, particularly in arid environments, by causing soil salinisation, blocking soil interstices with oil and grease, and accumulating heavy metals. So far, in most of the cases presented, the environmental impacts have been minor or undetectable. However, in Pakistan, over-applied wastewater with insufficient drainage (also the case with freshwater irrigation) has resulted in signs of degrading soil structure, visible soil salinity, and the delayed emergence of wheat and sorghum due to an excess of applied nutrients. Although such concrete impacts on soil are generally not yet measurable, these effects are likely to occur, given continued application and greater wasteloads. In some places such as Dakar, where groundwater is highly saline, if it were used for irrigation instead of wastewater, the impacts on soil could arguably be worse.

Change in Attitudes and Its Implications

Notwithstanding these impacts, attitudes towards wastewater use are changing among researchers and policy makers. First, there is a growing recognition that its use can also generate some positive health impacts. Food security is enhanced for both producers and consumers, as the increased agricultural output generates higher incomes for farmers, and provides more affordable fresh fruits and vegetables to the poor. In both cases, this increased food security can combat malnutrition, a leading factor in half of the deaths of children in developing countries (WHO, 2000), and also a cause of stunted physical and

cognitive growth (Berkman *et al.*, 2002, cited in Carr *et al.*, Chapter 4, this volume). Increased incomes are associated with better health, even when wastewater irrigation leads to more disease risks. Carr *et al.* reference a study in which a village with a rice irrigation scheme had more malaria vectors than a nearby village in Tanzania, but a lower level of malaria transmission – because the first village had more resources to buy food, children were better nourished, and the villagers could afford mosquito nets (Ijumba, 1997, cited in Carr *et al.*, Chapter 4, this volume).

Second, even those updating the World Health Organization (WHO) *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture* (WHO, 1989) acknowledge that at times the current guidelines may be too strict. In the analysis presented by this volume's theme papers, Fattal *et al.*, conclude in Chapter 5 that the current WHO wastewater effluent guidelines provide a safety factor one to two orders of magnitude greater than that called for by the United States-Environmental Protection Agency (USEPA) for microbial standards for drinking water. The paper by Richard Carr of the WHO (Carr *et al.*, Chapter 4, this volume) makes clear that managing health risks should be a holistic exercise, accounting for risks from all water-related microbial exposures. Future WHO guidelines will be based on the Stockholm Framework (Carr *et al.*) which suggests that countries adapt the guidelines to their own social, economic, and environmental circumstances. This framework requires that the risk of gastrointestinal illness be considered *within the context of all possible exposures*, including water supply, sanitation and contaminated food, which facilitates decision-making that addresses the greatest risks first. As an example, Fattal *et al.*, provide estimates that show for a city of one million using untreated wastewater, that treating the wastewater to the current WHO unrestricted guidelines would cost US$125 per incidence of disease prevented. From a health perspective, the question here is whether some other measure applied to improving water supplies, or towards health education, could be equally or more effective at preventing disease, at a lower cost.

An example in this volume given by Carr *et al.* (Chapter 4) helps demonstrate the point that full wastewater treatment is not necessarily the most cost-effective way of protecting public health: consider a river basin in which the background level of acute gastrointestinal illness is 0.8 episodes per person per year – the typical rate amongst adults worldwide. In this case, using wastewater treated to the current WHO guidelines (10^3 faecal coliforms (FC)/100 ml) in urban farming would, at maximum, increase the incidence rate to 0.8001 episodes per person annual. Such a small difference is undetectable, and contributes virtually nothing to the background level of diarrhoea. In other words, there is no additional increase in risk associated with using wastewater treated to the current WHO standard. In contrast, the use of untreated wastewater, which contains about 10^8 FC/100 ml, could increase the incidence of diarrhoea by up to 76%, i.e. to about 1.4 episodes/person/year. Almost doubling the risk level by using untreated wastewater may be inappropriate, but with limited funds, it may simply be too expensive to pursue a policy of zero incremental risk by treating to the current WHO guidelines. In such cases, it may be pragmatic to accept a level of risk that is lower than one from using untreated wastewater, but that is slightly higher than the typical background level of illness. For example, one could follow instead the suggested future WHO restricted irrigation guideline of treating the wastewater to the level of 10^5 FC/100 ml, which necessitates a lower level of treatment than the current ones. The money saved by not adopting full treatment could then be more effectively spent on other measures to reduce gastrointestinal illness, such as improving drinking water quality. An extreme example from the southern Punjab in Pakistan illustrates this point: in this basin, where the only source of drinking water is from irrigation canals with *Escherichia coli*/100 ml, levels that far exceed the WHO drinking water standard (Carr *et al.* Chapter 4, this volume), it would be inappropriate to expect that the wastewater be treated to a higher quality than the water that people are drinking.

In an ideal world, policy decisions would be made based on scientific analysis showing the actual risk levels, as described above. However, public perception of risk must also be considered. While serious chronic gastrointestinal

illnesses such as amoebic dysentery, roundworm, and hookworm, are endemic throughout the developing world, large-scale epidemics and serious illnesses such as cholera and typhoid have been less common. Past cholera epidemics isolated to raw wastewater use, such as the ones that occurred in 1970 in Jerusalem, 1984 in Dakar, and 1983 in Santiago, have faded from public memory. Yet, global public awareness of health impacts will have a greater reach today than in 1984, due to the advances in information and communication technologies made in the last 20 years. In effect, an epidemic would quickly generate worldwide publicity through the Internet, and magnify local knowledge of the issue. The public reaction to the 2003 SARS epidemic greatly exceeded the actual risk level, and generated devastating impacts on the economies of affected cities, including Hong Kong, Hanoi, and Toronto. For this reason, although Saudi Arabia's ban on vegetable imports from Jordan (see McCornick *et al.*, Chapter 14, this volume) may be dubious from the viewpoint of scientific risk assessment, it is understandable from a political viewpoint, in terms of the impact that negative public perception could have. Furthermore, awareness of the risks associated with consuming contaminated produce is growing within industrialised countries. For instance, 23% of the fresh fruits and vegetables consumed by Americans are imported, and this figure is growing. A recent *New York Times* article (Burros, 2003) stated that contaminated green onions imported from Mexico were linked to recent outbreaks of hepatitis A, which killed three people and sickened hundreds. The same article made reference to recent outbreaks of food-borne illness traced to Guatemalan raspberries, and to salmonella that was traced to Mexican cantaloupes (Burros, 2003). Even if actual risk levels are low, media attention and public reaction could spell trouble for developing countries, whose food exports may be irrigated with wastewater.

Even farmers in countries that do not export vegetables could suffer devastating impacts, if another crisis generated enough publicity so that the public, including tourists, refused to consume vegetables that may or may not have been irrigated with wastewater. Several agencies including the Ghana Tourist Board, have expressed concerns about the hygienic cultivation of vegetables in Ghana, and launched a campaign for safer vegetable production (Sonou, 2001). Thus, another tradeoff that must be addressed is the public perception of risk versus the actual risk.

It becomes clear that in seeking realistic solutions, policy-makers must account for both untreated and treated wastewater use, and make policy choices that protect farmers' livelihoods and the public health. Bharmoriya's Chapter 11, this volume neatly illustrates the conundrum: About 100 villages downstream of Vadodara practise untreated wastewater use, as they have few other options to support their livelihoods. This generates about US$5.5 million annually, but the practice threatens their own health, and that of the roughly 1.5

Table 16.1. Timeframe for meaningfully implementing recommendations in the least developed countries (LDCs).

Recommendation	Timeframe for meaningful implementation
Develop and apply guidelines	Medium to long term
Treat wastewater and control at source	Medium to long term
Apply other management options	
• Increase farmer and public awareness	Short to medium term
• Minimise human exposure	Short to medium term
• Treat infections	Short to medium term
• Use safer irrigation methods	Short to medium term
• Restrict crops	Short to medium term
• Improve institutional coordination	Medium to long term
• Increase security of land tenure	Medium to long term
• Increase funding	Short, medium and long term
Conduct research	Short, medium and long term

million residents in and around the city. The following section suggests recommendations to tackle such difficult cases as this one.

Recommendations

The following recommendations, summarised in Table 16.1, are organised into four categories: develop and apply guidelines, treat wastewater and control at source, apply other management options, and conduct research. Note that Table 16.1 also outlines when each recommendation can be meaningfully implemented in the least-developed countries.

Depending upon the context and stakeholder views, it is suggested that policy-makers take a holistic and integrated approach, and act immediately on those recommendations requiring little or no further study. For instance, in Tunisia, where risk of exposure from drinking water sources and contaminated food is low, appropriate guidelines are already in place, and Shetty *et al.* (Chapter 15, this volume) outline that the focus there ought to be on continuing improvement of institutional coordination, increasing farmer education, and safer, more sustainable irrigation methods. Similarly, in Jordan, a major focus should be on improving institutional coordination, and on collecting and treating wastewater with improved source control – part of which is occurring through the expansion of the As-Samra wastewater treatment plant. In contrast, poorer countries in Latin America, Asia and Africa, such as Bolivia, Pakistan, and Senegal, will need more time to develop the guidelines for collecting and treating wastewater, with appropriate source controls. Therefore, to minimise the risks to public and farmer health, it is essential to increase awareness amongst affected groups, and with this added knowledge, to begin minimising human exposure, to treat infections, and to use safer irrigation methods.

In other words, countries can and should begin work on all recommendations concurrently, but it is acknowledged that in the least-developed countries, it will take time to develop and implement both guidelines and affordable treatment. However, many of the management options can be acted on immediately, with visible benefits to the most marginalised groups. In the poorer countries in particular, it is essential to practice what is in effect a multi-barrier approach, because it is unlikely that one measure alone will protect both farmer and public health. More details on each recommendation are discussed below.

Develop and apply holistic and appropriate health guidelines

It is essential for countries to develop guidelines that are adapted to their individual social, economic and environmental context. This means following the Stockholm Framework and the impending revised WHO guidelines, which recommend assessing the risks associated with wastewater use in agriculture within the context of the actual disease rates of the population from all sources, including water supply, sanitation, and contaminated food. Mexico is a case in point, where the WHO guidelines were adapted to reflect local conditions. As risk factors may vary from river basin to river basin within a country, so may the guidelines. Taking a holistic and flexible approach also means that the guidelines will change over time. As the relative risk factors change – for instance, when water supply and sanitation improve – the guidelines for wastewater should become accordingly more stringent. For greatest impact, the guidelines should be implemented with other health measures, such as health education, hygiene promotion, and the provision of adequate drinking water and sanitation. Positive health impacts arising from wastewater use, such as the resulting improved nutrition due to greater household income and food security, should also be duly considered.

Treat wastewater and control at source

Focusing as much as it is economically feasible at the start of the wastewater use chain will reduce downstream problems. This entails domestic treatment, but whether this requires higher levels of treatment for unrestricted use, or lower levels for restricted use, depends principally on whether vegetables are eaten

raw or not. In most cases, treatment will necessitate collecting and treating wastewater in decentralised plants that focus less on environmental pollutants, such as suspended solids and biochemical oxygen demand (BOD), and more on pathogens. The paper by Silva-Ochoa and Scott, Chapter 13, this volume, demonstrated that treatment plants are still being built without consideration of the benefits of use in UPA. Waste stabilisation ponds and chemically enhanced primary treatment with sand filters are two examples of methods that have proven efficient in protecting public health, while being less costly than traditional mechanical, secondary treatment plants. The oft-repeated refrain that treatment is too expensive is questionable – if the Stockholm Framework is properly applied, then in many countries the required standards will actually result in falling costs for the necessary treatment. Furthermore, as shown, farmers are increasingly prepared to pay for wastewater, so financing can be some mix of polluters and users pay principles. It is estimated that levying pollution taxes for only 10% of generated wastewater in Ghana, could bring in up to US$38 million annually (Agodzo, personal communication).

While treatment to meet appropriate guidelines may not yet be feasible in all cases, it should still be one of the desired end results. This however, does not preclude phasing in better treatment over time and progressively providing increased risk reduction, with the goal of eventually arriving at the ultimate target of full treatment. In Pakistan, where most irrigated vegetables are eaten cooked and the main health impact is hookworm in farmers, encouraging the use of footwear by farmers and gloves by crop handlers is more important at this stage than full treatment. Partial treatment would likely bring risk levels down to acceptable levels, and could be as simple as irrigation storage reservoirs, as outlined by Carr *et al.*, which have been proven to reduce risks to farmers and their families in Mexico to minimal levels. In this case, following a hypothetical strategy suggested by Carr *et al.*, Chapter 4, this volume, initial standards could be set at 10^5 FC/100 ml and 50 nematode eggs/l. This standard could be attained using irrigation storage reservoirs with sufficient retention time to allow the pathogens to die off. As resources become available to build additional treatment facilities, and as risks of disease from the water supply or contaminated foods fall, the standards could be tightened to 10^4 FC/100 ml and 10 nematode eggs/l, which could be met with natural primary treatment and storage reservoirs. Eventually, the standard could reach the current recommendation of 10^3 FC/100 ml and 1 nematode egg/l, which can be met by a waste stabilisation pond that provides secondary treatment, with sufficient retention time, disinfector, or polishing slow-sand filters. Inherent in this recommendation is the need to work with industries, institutions, and municipalities, in order to control industrial and toxic contaminants, such as heavy metals, at source. As Silva-Ochoa and Scott note in Chapter 13, it is also important to ensure that treatment does not shift sole access to the resource from poorer farmers, who currently depend on untreated wastewater, to more powerful farmers, or private organisations such as golf courses.

Apply other management options

Increase farmer and public knowledge and awareness

Education programmes for all stakeholders, including farmers, the public, and policy-makers, are essential complements to other risk-reduction tools. The findings in this volume can help stakeholders confront realities, and can form the basis for awareness-raising strategies, including discerning the extent of wastewater use, the extent to which farmers' livelihoods depend upon the practice, and both the positive and negative health impacts within the overall health context of the population. This should be followed by the application of mitigation strategies in line with the WHO guidelines, especially those under the control of the individual stakeholders, such as the wearing of shoes by farmers, and the adequate cooking of produce by consumers. In order to ensure that awareness strategies are relevant and sustainable, both secular tools such as schools and media campaigns, along

with culturally appropriate non-secular tools, need to be used for such strategies to be comprehensive and broad-based. A comprehensive public awareness programme would likely also bring actual and perceived risk levels closer in line, lessening the chance that unnecessarily strict guidelines would be adopted, which could drain a country's limited financial resources without resulting in greatly improved public health.

Minimise human exposure

The WHO has outlined preventive measures for groups potentially at risk from the use of wastewater in agriculture, including farmers and their families, crop handlers, consumers, and those living near the fields. The first two groups are especially susceptible to helminthic infections, so for protection, health authorities can encourage the use of shoes and gloves. Field workers need to be provided with potable water for drinking and hygiene. Similarly, produce vendors should use safe water for washing and rinsing produce – it is ineffectual to protect the crops in the fields if they are contaminated in the market. Finally, consumers should wash and cook vegetables and meats thoroughly, and maintain good hygiene practices. Consumers aware or suspecting that produce is contaminated should soak it in a disinfectant such as sodium hypochlorite or potassium permanganate. Of course these measures in themselves carry risks if the concentration of the disinfectant is excessive, so as always, it is essential for public health departments to underpin all of these measures with comprehensive health and hygiene education campaigns aimed at all stakeholders.

Treat infections

Infection with helminths is the most important health risk associated with wastewater use. In cases where even partial treatment is not possible, and where time is needed to implement other management options, effective health protection may be provided by regular mass treatment of exposed people with anthelmintic drugs. This is especially so if the communities of wastewater farmers are localised, and rather homogeneous. Of course the repeated treatment with safe, single-dose, affordable anthelmintic drugs is a short-term approach, but one that can provide immediate health benefits

Use safer irrigation methods

Irrigation methods can affect both the degree of plant contamination, and the types of precautions farmers can take. In Dakar, the principal method of irrigating with watering cans intensifies the risk of contamination, because droplets touch the plant leaves, while in Pakistan, over-irrigation in furrows without adequate drainage creates an ideal environment for hookworm infection. Localised irrigation techniques such as drip or trickle irrigation are the safest, because the wastewater is applied directly to the root zone of the plants. As an added benefit, this also reduces water consumption. Such techniques require treatment to reduce suspended solids that clog the openings, or the use of drip irrigators with fairly large holes. The treatment can be simple and inexpensive – storage reservoirs that allow suspended solids to settle out may be sufficient. Although drip irrigation is generally the most expensive to implement, some farmers in middle-income countries like Jordan (Faruqui and Al Jayyousi, 2002) are already using this method, and even some in lower-income countries such as Cape Verde and India (FAO, 2001) are doing so as well. Furthermore, low-cost drip irrigation systems such as the 'drum and bucket' that International Development Enterprises (IDE) has tested in Kenya and Zimbabwe have proven successful. Such schemes can be affordable if donors step forward with micro-credit projects to fund this small-scale infrastructure.

The timing of wastewater use can also reduce health impacts. Tunisian standards follow the WHO guideline recommendation that wastewater irrigation be stopped two weeks before harvest. However, this may not always be feasible for farmers without an alternate source of irrigation, as crops will literally wither in the field, particularly during hot and dry times of the year. In such cases, the waiting time period would have to be shortened.

Restrict crops

Crop restrictions can be used where water of sufficient quality is not available for unrestricted irrigation. While crop restrictions can protect consumers, they do not protect farmers and their families, so this measure cannot be applied on its own. Crops restrictions have proven most feasible (for example in Mexico, Peru, and Chile) (Blumenthal *et al.*, 2000), in situations when an irrigation project is centrally managed, strong law enforcement exists, and most importantly, when the crops allowed under the restrictions are profitable. For instance in Haroonabad and Faisalabad, Pakistan, farmers are happy to produce vegetables that are usually eaten cooked, because high demand makes these crops most profitable. In this case, crop restrictions are unnecessary, because there is no strong incentive to produce vegetables eaten raw. In cases when restrictions alone are impractical, such measures must be combined with a methodical public awareness and farmer education programme. In this way, if regulation fails, increased public awareness and market forces may succeed, as there may be reduced consumer demand to purchase vegetables eaten raw that are irrigated with wastewater.

Integrate guidelines and improve institutional coordination

The cases illustrate that health, agricultural, and environmental guidelines often overlap, and sometimes even conflict. Furthermore, there is a lack of collaboration between non-governmental organisations, for example, farmer groups, and those at different levels of government, from municipalities to national departments, including such entities as the Ministries of Agriculture, Health, and Urban Planning. It is essential that all stakeholders be brought together to find mutually satisfactory solutions – based on public input and the Stockholm Framework – policy-makers can then develop integrated health, agricultural and environmental quality guidelines, and implement them in partnership with communities. Although there are still some problems with Tunisia's organisational setup, as outlined by Shetty *et al.* (Chapter 15, this volume) the country has merged the Ministries of Agriculture, Environment, and Water Resources in a new super ministry that now manages water (including wastewater) in a more integrated manner.

Increase security of land tenure

To seriously confront the reality of wastewater use, and to have any lasting positive impact on the health of farmers, the issue of land reform needs to be included as an essential component of any integrated policy. At present, both farmers using wastewater and those using freshwater are already practicing UPA on thousands of hectares of undeveloped public land in and around cities. Often the issue is not the availability of the land, but rather the lack of an authoritative guarantee for its use for a specific period of time, without the threat of sudden expulsion. In exchange for this added security, farmers may even be willing to pay to lease the land, if they are not already doing so. It is unlikely that insecurity of tenure is preventing farmers from taking steps to minimise their exposure, such as buying shoes, gloves or medicine. However, secure tenure is more likely to increase the propensity of farmers to invest in land and irrigation improvements, and some such as localised irrigation systems – whether simple drum and bucket systems, or hoses, pumps, and drip irrigators – have additional protective health benefits. Land reform would also facilitate the building of storage reservoirs, a simple method of treatment that carries the additional benefit of helping balance irrigation water supply with demand. In many cases, these would have to be built on farmers' land, and neither the state nor farmers are likely to build decentralised treatment or storage facilities on land of uncertain status.

Increase donor/state funding

Ideally, polluters (both industry and households), governments, farmers, and consumers, would all pay a share of the costs needed for safe and sustainable UPA that protects the environment and public health, and that enhances food security and nutrition. Polluters

and governments alike should pay for the cost of treatment. Farmers should pay for access to the irrigation water, and for drip irrigators that protect their own and consumer health, recouping some of these costs from the consumers who pay for their produce. Farmers can also be reasonably expected to contribute to a portion of the cost for decentralised treatment, if it is close to or on their land.

Cost sharing may be a realistic medium-term scenario, but only if all stakeholders are convinced of the benefits stemming from policy measures such as wastewater treatment, or the implementation of safer irrigation systems. Farmers may be more willing to contribute if the benefits of such measures are first demonstrated to them. Governments may also be more willing to contribute to the cost of implementing the above recommendations after realising the economic and employment impacts arising from food markets, and the improved nutrition associated with UPA that uses wastewater. However, this requires investment before the fact, to bring services up to a standard to which all stakeholders are willing to contribute. During this transition period, it is crucial for foreign aid donors to step in to provide the initial funds, in order to prove to both farmers and policy-makers that the benefits of UPA can be realised without excessive health risks. Without additional funding, many of the recommended options cannot be meaningfully implemented.

Conduct research

Due to the informal and quasi-illegal nature of wastewater irrigation, and the cost and time required to do methodical research, many findings to date only probe the surface. More profound and methodical research will be necessary if the issues related to the realities of wastewater use are to be brought onto the global agenda. Chapter 8 by Ensink *et al.*, is a good model of comprehensive scientific, research on wastewater use in a particular case, while Buechler's Chapter 3 outlines useful suggestions to ensure that research is centred on the livelihoods of farmers, the principal actors in this play, while also capturing all social, economic, and political aspects. In fact, research needs to be participatory, and account for farmers' concerns, perceptions, and practices, if the research results are to be implemented in a sustainable fashion. Some key research gaps that must be addressed before the above recommendations can be meaningfully implemented include:

- testing the feasibility and cost-effectiveness of non-treatment management options;
- designing efficient, cost-effective, and sustainable natural wastewater treatment systems that conserve nutrients while effectively removing pathogens;
- identifying incentives for industrial effluent separation and treatment;
- developing appropriate standards and guidelines to protect public health in different contexts;
- finding the best institutional policies, frameworks, and implementation mechanisms to help municipal and national institutions work together to support urban farmers and protect public health; and
- investigating the political economy of wastewater use in UPA, including analysis of inequitable access to irrigation sources and land.

In addition, in order to attract increased donor and state funding, information on the following topic is required.

Value-addition of wastewater use

Better economic estimates of the value of UPA that uses wastewater will emphasise its importance for poverty alleviation to donors and policy-makers. Researchers have only been able to present vague economic estimates on the benefits and costs of UPA, and most donors and policy-makers are completely unaware of the degree of urban farming and its importance to the national economy. For instance, in Pakistan, 26% of the vegetables produced are grown using wastewater (Ensink *et al.*, Chapter 8, this volume). Decision-makers need hard estimates of the total area cropped, the annual production of different types of crops produced, and their monetary values. This could then be compared to the total amount produced in rural agriculture. Once its economic significance is realised, both donors

and policy-makers are likely to pay more attention.

One important missing area of research is a comprehensive guide to the economic impact of wastewater use that goes beyond the employment and nutritional benefits discussed above. Some attempts have been made to develop frameworks for such an analysis (Hussain *et al.*, 2001) but there is little information on the economic externalities associated with discharging wastewater into water bodies and wetland systems that have downstream beneficial uses. Little work has been made on savings in treatment costs associated with land application of wastewater, or income-generating opportunities derived from agricultural use. The results of such analysis could potentially impact the way in which wastewater agriculture is viewed. Research on household greywater reuse in Jordan has demonstrated that the benefit-cost ratio of reuse for agriculture is as high as 5 (Faruqui and Al Jayyousi, 2002). Also needed is a similar examination of semi-collective treatment systems, on which policy recommendations can be based. Ensink *et al.* (2004) provided an innovative way of estimating the value of land accessible to farmers, by identifying the higher rents for land having access to wastewater for irrigation, as compared to land that is irrigated with freshwater. However, more work is needed on this aspect of wastewater use.

Conclusions

The deepening integration of today's food markets makes the use of wastewater in agriculture a vital issue for all countries to address, and this recognition must start with the acknowledgement that the practice is already widespread, and contributes much more to farmers' livelihoods and to food security than is commonly understood. In some cases, farmers would be unable to earn a living without using wastewater, and for others, its use increases the income they would normally make, lifting them out of poverty. However the practice often threatens the health of the farmers, their families, the broader public, and the environment. Policy-makers must find a way to protect both farmers' incomes as well as public health, in a way that is economically sustainable. This volume was inspired by a workshop in Hyderabad, India, in November 2002, at which researchers, and policy-makers brainstormed potential options, and offered some suggestions, encapsulated in the *Hyderabad Declaration on Wastewater Use in Agriculture* (Appendix 1, this volume).

These realisations have changed the views of policy-makers, even among those involved in setting the initial 1989 WHO guidelines. The newly emerging ones recommend that guideline setting be a holistic risk-analysing exercise, adapted to each country's social, economic, and environmental circumstances. This would entail taking into account background levels of gastrointestinal illness, and allocating scarce health protection dollars to the highest priority. An integrated set of measures, that collectively form a multi-barrier approach to protect health is also suggested, including progressively phased-in treatment, and other management options. These encompass raising public awareness, using safer irrigation methods, minimising human exposure, restricting crops, disinfecting of produce by consumers, institutional coordination, increasing land tenure, and increasing funding. Finally, in order to achieve meaningful implementation, and to secure the necessary funding from donors, further research must be done to evaluate the feasibility and cost-effectiveness of the above suggestions, and to establish better estimates of the economic value of wastewater use in urban and peri-urban agriculture.

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Appendix 1

The *Hyderabad Declaration on Wastewater Use in Agriculture*
14 November 2002

1. Rapid urbanisation places immense pressure on the world's fragile and dwindling fresh water resources and over-burdened sanitation systems, leading to environmental degradation. We as water, health, environment, agriculture, and aquaculture researchers and practitioners from 27 institutions and representing experiences in wastewater management from 18 countries recognise that:
   1.1 Wastewater (raw, diluted or treated) is a resource of increasing global importance, particularly in urban and peri-urban agriculture
   1.2 With proper management, wastewater use contributes significantly to sustaining livelihoods, food security and the quality of the environment
   1.3 Without proper management, wastewater use poses serious risks to human health and the environment.

2. We declare that in order to enhance the positive outcomes while minimising the risks of wastewater use, there exist feasible and sound measures that need to be applied. These measures include:
   2.1 Cost-effective and appropriate treatment suitable for wastewater, supported by guidelines and their application
   2.2 Where wastewater is insufficiently treated, until treatment becomes feasible:
      - Development and application of guidelines for untreated wastewater use to safeguard livelihoods, public health and the environment
      - Application of appropriate irrigation, agricultural, post-harvest, education and public health practices that limit risks to farming communities, vendors, and consumers.
   2.3 Health, agriculture and environmental quality guidelines that are linked and implemented in a step-wise approach
   2.4 Reduction at source of toxic contaminants in wastewater.

3. We also declare that:
   3.1 Knowledge needs should be addressed through research to support the measures outlined above
   3.2 Institutional coordination and integration together with increased financial allocations are required.
4. Therefore, we strongly urge policy-makers and authorities in the fields of water, agriculture, aquaculture, health, environment and urban planning, as well as donors and the private sector to:

Safeguard and strengthen livelihoods and food security, mitigate health and environmental risks and conserve water resources by confronting the realities of wastewater use in agriculture through the adoption of appropriate policies and the commitment of financial resources for policy implementation.

Index

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