IWMI Research Report

147

Urban Wastewater and Agricultural Reuse Challenges in India

Priyanie Amerasinghe, Rajendra Mohan Bhardwaj, Christopher Scott, Kiran Jella and Fiona Marshall

IWMI International Water Management Institute

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Front cover photograph shows two women watering a spinach plot with wastewater in peri-urban Hyderabad, India (*photo credit*: Priyanie Amerasinghe).

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Contents

Acronyms and Abbreviations

ADB	Asian Development Bank
ASP	Activated Sludge Process
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CoI	Census of India
CPCB	Central Pollution Control Board
ECW	East Calcutta Wetlands
FAO	Food and Agriculture Organization of the United Nations
GAP	Ganga Action Plan
mg	milligram/s
µg	microgram/s
mld	million liters per day
mly	million liters per year
MPN	Most Probable Number
NRCD	National River Conservation Directorate
RS	Remote Sensing
RQ	Risk Quotient
SAR	Sodium Adsorption Ratio
STP	Sewage Treatment Plant
WHO	World Health Organization

Summary

Urban wastewater management has become a challenge in India as infrastructural development and regulations have not kept pace with population growth and urbanization. Annually, more and more people are moving into cities, and the figures are expected to reach about 600 million by 2030 making India more peri-urban than rural. Already, there is enormous pressure on planners to provide utility services, and water supply is a priority, especially where peri-urban water is exported formally or informally to fulfill city requirements. At the same time, the urban return flow (wastewater) also increases, which is usually about 70-80% of the water supply.

This study attempted to analyze the current status of wastewater generation, its uses and livelihood benefits especially in agriculture, based on national data and case studies from Ahmedabad, New Delhi, Hyderabad, Kanpur and Kolkata.

The challenge of the growing Indian economy is that, in many cities, the wastewater generated is a mixture of domestic and industrial wastewater which makes risk mitigation and reuse recommendations a challenge. Lack of systematic data on the different discharges makes it difficult to estimate the volume and quality of wastewater discharged and the total area under (usually informal) wastewater irrigation. Data from more than 900 Class-I cities and Class-II towns (with the population of each over 1 million and between 0.5 and 1 million, respectively) showed that more wastewater gets collected than eventually treated. In general, wastewater generation is around 60-70% over the established treatment capacity which varies from city to city. Governmental efforts to reduce surface water pollution remain jeopardized by the untreated wastewater fraction as well as by India's estimated 160 million latrines and septic tanks which contribute, according to Centre for Science and Environment (CSE), to 80% of the pollution of the national surface waters. The way forward will have to be built on further investments in treatment capacity for septage collected from on-site sanitation units, and in particular for industries to avoid interference in domestic and industrial waste streams. Reuse could offer business opportunities for cost recovery, while in smaller towns options like riverbank filtration, reed bed technologies and phytoremediation should also be explored to turn the waste stream into a resource. From the data set used for this study, it is evident that over 1.1 million ha could be irrigated if rendered safe for use.

The major users of wastewater in the study sites include growers of cereal (like rice), horticultural and fodder crops and aquaculture (mostly in East Calcutta Wetlands [ECW] and also in Delhi), and to a lesser extent floriculturists. In Delhi and Kanpur, treated water was issued by farmers for agricultural production. However, with time the quality of wastewater had deteriorated, especially in Kanpur and it was no longer suitable for crop cultivation. In Hyderabad, although the government did not support the use of partially treated wastewater for irrigation, the farmers used it as it was the only source of water downstream of the city. Industrial pollution was highest at Kanpur and Ahmedabad so that both water quality and crop quality were affected at the heavily polluted sites. Data from the selected sites show that the financial benefits associated with wastewater farming were higher than those associated with freshwater-agriculture for cities where domestic wastewater does not mix with industrial sewage. Also, adverse health and environmental impacts were lower in such cities. The highest gains were reported from the ECW, where sewage farming has been practiced for

over a century. However, a more holistic analysis which includes all household expenses like health, food, etc., and considers both direct and indirect costs and benefits would be required to calculate the net benefits. Particular attention is required to assess the effects of hazardous contaminants on water, soil and crops. Health risk assessments from most cities showed that wastewater farmers were more vulnerable than others to certain diseases and environmental hazards. However, site-specific health risk assessments are needed to investigate the short- and long-term health impacts of wastewater, so that effective remedial measures could be adopted.

Given the increasing peri-urban character of India, this study showed that wastewater management needs much more attention than it has received so far. This is required from the perspectives of both health and water resources management. With nearly 70% of the population projected to live in cities, and water scarcity being reported from many parts of the country, planners need to have a strategy on how best to utilize the various water resources, including untreated, partially treated and fully treated wastewater, for different productive purposes. Monitoring and data collection are increasing in India but they must be carried out in a systematic manner. Institutionalizing the proposed data collection template which links into an extended AQUASTAT database could help collect uniform data sets for strategic planning.

Urban Wastewater and Agricultural Reuse Challenges in India

Priyanie Amerasinghe, Rajendra Mohan Bhardwaj, Christopher Scott, Kiran Jella and Fiona Marshall

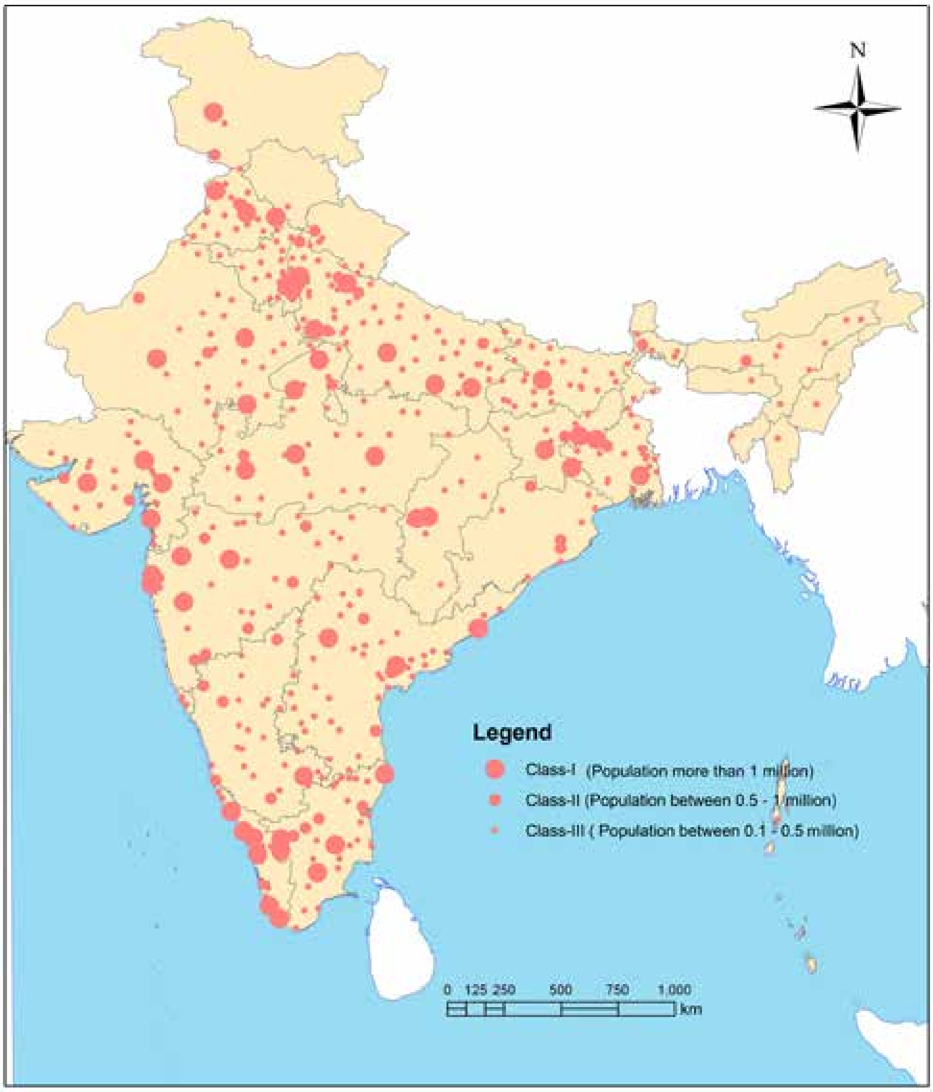
Introduction

India's urban centers are witnessing unprecedented growth, propelled by new economic reforms. Its population, which is over one billion, is now fast converging on cities in search of opportunities and a new way of life. According to recent projections, India's urban population of 380 million (2008) is expected to increase to 590 million by 2030, twice the current population of USA (MGI 2010), with regional cities expanding at a faster rate than the larger cities. Increased migration of people to cities already exerts enormous pressure on city planners, especially for provisioning utility services. Already, many cities can be now considered as 'sponges' absorbing water from peri-urban and rural areas through formal and informal channels (Van Rooijen et al. 2005; Molle and Berkoff 2009; CSE 2012). In general, public services and infrastructural development are not keeping pace with urbanization, and indeed they may become a constraint on economic growth. Feeding the cities will also become a major challenge, where more and more food supplies will have to be brought from distant rural places, increasing costs and food prices (Hanjra and Qureshi 2010). On the other hand, the increasing urban 'return flow' is posing health challenges as well as production opportunities for feeding the cities.

Sectoral Demands for Water

Sectoral demands for water are reaching new heights where irrigation, household supply, energy and industry seek increased volumes to meet growing needs. The 2050 projections for India report that it will reqire 1,447 cubic kilometers (km^3) of water of which 74% is identified for irrigation, while the rest is for drinking water (7%), industry (4%) energy (9%) and others (6%) (CPCB 2009). However, with rapid urban growth in its 498 Class-I cities and 410 Class-II towns (CoI 2001), the demand for drinking water is also rising and has a high priority, competing with rural water needs, including irrigation. The current water supply to these cities is estimated at about 48,000 million liters per day (mld) and is projected to increase further with the increased demand for different sectors (CPCB 2009). A large number of these growing cities are located in major river basin catchments, taking freshwater away and discharging wastewater back into the catchments and thus polluting irrigation water as well as posing major challenges for urban and rural planners, especially with regard to urban wastewater management. In fact, the density of the emerging cities makes India today more peri-urban and urban than rural (Figure 1). That the urban return flow is seen not only as a hazard but also as an asset was just recently documented in

FIGURE 1. Distribution of Class-I cities, Class-II towns and Class-III towns in India in 2011.



Source: CoI, 2011.

the struggle between Karnataka and Tamil Nadu for Bangalore's wastewater (Raghunandan 2012).

Wastewater Generation and Treatment

Despite the keen interest of the government, infrastructural development for sewage and wastewater treatment has not kept pace with wastewater generation. As a result, vast amounts of polluted water are being discharged into natural waterways, with poor-quality water and pollutants above the permissible levels being released into the environment (MoEF 2009). Studies have shown that farmers living close to cities have had to change their crops to suit the declining quality of irrigation water (Buechler and Mekala 2005). Proactive adaptation to water-quality issues increases the cost of production while suboptimal crop choices reduce benefits of livelihoods to these farmers. With many components of the water cycle being affected for years and the increasing water demand for cities, there is a sense of urgency to explore sustainable water management strategies, while looking into the multiple uses of wastewater and alternative wastewater treatment technologies (Lorenzen et al. 2010).

In many Indian cities, the wastewater discharges comprise domestic and industrial wastewater, and are often mixed and not separately accounted for. Lack of systematic record-keeping of the different discharges makes it difficult to arrive at reasonable estimates of the wastewater discharged and its quality (Heggade 1998; Misra 1998). For the period 1947-1997, a sixfold increase in wastewater generation was recorded in Class-I cities and Class-II towns. Current generation for Class-I cities and Class-II towns is above 38,000 mld, out of which only 35% is treated (CPCB 2009).

Conservation, augmentation and recycling of urban water are major foci in India's national water policy. The policy also advocates the reuse of treated sewage in view of the looming water-scarce future. Thus, the policy support for reuse of treated wastewater, primarily from sewage treatment plants (STPs), is inherently embedded in the overall water policy of India, although in practice, multiple factors affect its implementation at state level. The Ganga Action Plan (GAP) was one of the first restoration plans for water bodies, which commenced in 1985 and led to a larger program bringing the entire country under the National River Action Plan. In this program, the identification of pollution sources, interception or diversion and treatment were planned for 157 major cities along the main rivers. However, fast urbanization and industrialization have outpaced the installation of STPs and regulatory processes and, therefore, only marginal improvements are observed.

Domestic sewage and industrial waste are the major causes of deterioration of water quality and contamination of lakes, rivers and groundwater aquifers (CPCB 2009). Septic tanks constitute one of the most common forms of urban sanitation facilities in India. The major part of urban India has not been connected to a municipal sewer system which makes people dependent on the conventional individual septic tanks. Access to improved sanitation in urban India has risen but the management of on-site sanitation systems such as septic tanks remains a neglected component of urban sanitation and wastewater management. There are around 100 million septic tanks and 60 million latrines in India (World Bank 2006) without treatment facilities for the generated septage which contributes to 80% of the pollution of the national surface waters (CSE 2011, 2012).

Based on water pollution, five different classes of water quality have been identified (Table 1). Data show that, from a 45,000 km length of Indian rivers, 6,000 km had a biological oxygen demand (BOD) above 3 milligrams per liter (mg/l), making the water unfit for drinking. Matters relating to sewage treatment as well as the drinking and industrial water supply are dealt with at state level while the municipal authorities of cities are responsible for providing these services. The regulatory standards are overseen by the state pollution control boards, which are linked to the Central Pollution Control Board (CPCB). Currently, only the networked sewage systems are targeted for treatment, while the vast non-point source discharges go undetected and untreated. Therefore, the pollution loads in rivers are highly variable, depending on the season, modulated by rainfall, sewage and solid waste management practices in towns and cities, and types of industry in the proximity. While the regulatory mechanisms have been outlined, uncontrolled industrial discharges contribute to heavy environmental pollution and potential health hazards (Rawat et al. 2009).

TABLE 1. Water-quality standards for India as per ISI-IS: 2296-1982.

Water use class	DO (mg/l)	BOD (mg/l)	Total coliform (MPN/100 ml)	pH	Free NH_3 (mg/l)	EC	SAR (mg/l)	Boron
Class A: Drinking without conventional treatment	6	2	50	6.5-8.5	NA	NA	NA	NA
Class B: Water for outdoor bathing	5	3	500	6.5-8.5	NA	NA	NA	NA
Class C: Drinking water with conventional treatment	4	3	5,000	6.5-8.5	NA	NA	NA	NA
Class D: Water for wildlife and fisheries	4	NA	NA	6.5-8.5	1.2	NA	NA	NA
Class E: Water for recreation and aesthetics, irrigation and industrial cooling	NA	NA	NA	6.5-8.5	NA	2.25	26	2

Source: CWC, 2010.

Notes: ml = milliliters; mg = milligrams; DO = Dissolved Oxygen; BOD = Biological Oxygen Demand; MPN = Most Probable Number; EC = Electrical Conductivity; SAR = Sodium Adsorption Ratio.

On the reuse side, the primary users of wastewater are smallholder farmers living in cities and peri-urban areas. Generally, they do not seek wastewater but use the water their streams and rivers carry. This can be water with different degrees of pollution, or wastewater of different degrees of dilution or natural cleaning or, raw sewage, especially in the dry season. In many situations wastewater is the only available or reliable water source (Buechler and Mekala 2005; Qadir et al. 2010). While the number of farmers dependent on wastewater is not well documented, more livelihoods are likely sustained through informal than formal wastewater-related activities (Raschid-Sally and Jayakody 2008). An inventory of wastewater-dependent livelihoods is however lacking in order to assess the wastewater-driven economies within India.

Against the backdrop of water scarcity and climate change, it is important to examine issues related to wastewater reuse more holistically, and to investigate the challenges and opportunities for its safe and efficient reuse. Many studies within India have documented site-specific contamination pathways and levels, as well as health risks, but they fall short of information on risk reduction and remediation along critical control points.

The goal of this study was to assess the scope of wastewater generation and reuse challenges in India. Specifically, the objectives were to provide estimates of wastewater generation and treatment, synthesize existing data on agricultural use of wastewater, and assess the related benefits and economic value, as well as the potentially adverse environmental and human-health impacts.

Study Sites and Methods

The study is based on primary and secondary data. In order to assess the wastewater generation across the country, secondary data were collected from relevant national-, state- and city-level institutions. Qualitative data were also collected from key informants including policymakers and institutional heads, using semi-structured interviews. To look at livelihood benefits and health impacts of wastewater use, five cities were selected as case studies. Availability of research data, infrastructure for wastewater treatment and access of wastewater to communities engaged in wastewater agriculture were the key criteria used for selection of the cities.

Based on the above criteria, Ahmedabad (in the Sabarmati River Basin), New Delhi (Yamuna River), Hyderabad (Musi River), Kanpur and Kolkata (both Ganga River) were selected (Table 2). For questionnaire surveys and focus group discussions, households were randomly selected from village communities near wastewater-carrying water bodies covering different castes, landholding statuses (leased or owned), and gender categories, so that different types of responses and perceptions were included. Focus group discussions and participatory rural appraisal methods were used to collect qualitative data and perceptions on livelihoods, health and environmental degradation. Data were collected on family size, literacy levels, wastewater irrigated crops and cropping patterns, input use, cost of production, crop productivity, irrigation practices, livestock holdings, health problems, extent of wastewater use and treatment, livelihoods supported, and economic aspects associated with the use of wastewater in livelihoods. Data were also collected on surface water/groundwater irrigated crop production within the vicinity, which served as a counterfactual for comparison. Laboratory studies on water quality, and secondary data from the case study sites were also used for comparison. The data collected were used for assessment of current wastewater generation and treatment, livelihoods, health impacts and cost-benefit analysis of agricultural production.

TABLE 2. Number of households surveyed in the selected study sites.

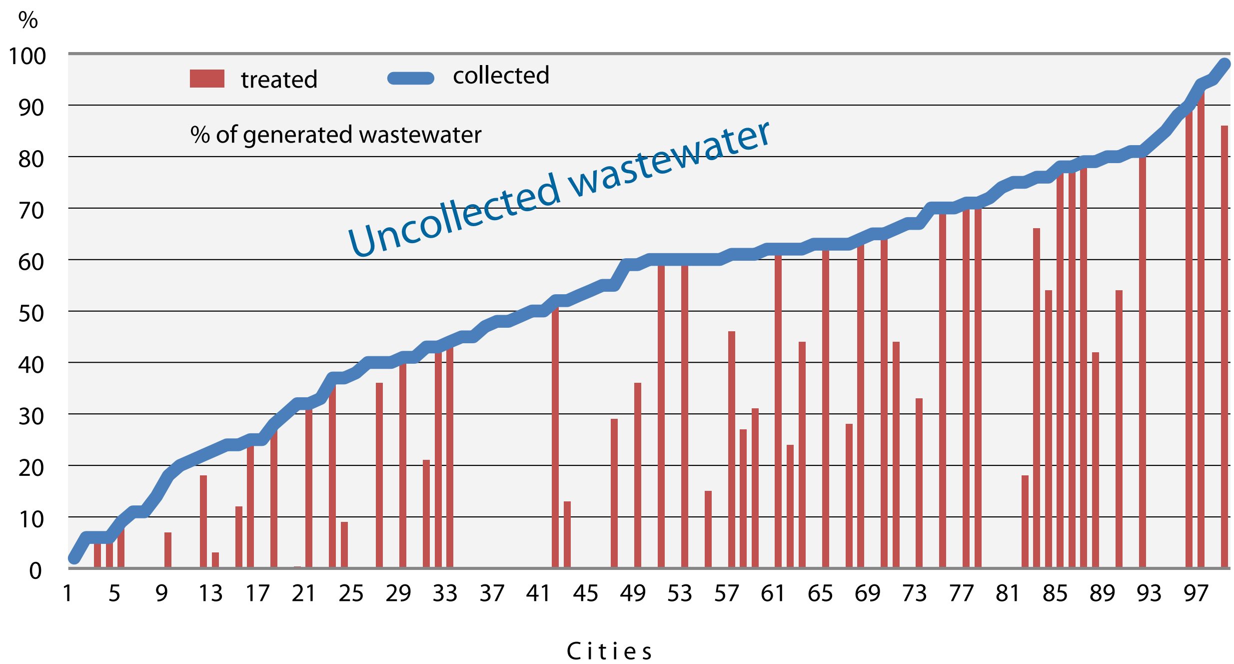
City/state	Study area (km^2)	River basin	Villages	Households (n)
Ahmedabad/Gujarat (230 25' N and 720 55' E)	205	Sabarmati	Gyaspur, Asamli, Bakrol, Chitrasar, Fatehpura, Navapura, Rinza, Saorda and Vautha	289
Delhi/National Capital Territory (280 36'36" N and 770 13'48" E)	1,484	Yamuna	Keshopur, Nilauthi, Ranhaula, Mundka, Bakkarwala) and Okhla STP (Madanpur Khadar and Jaitpur)	80
Hyderabad/Andhra Pradesh (170 45' N and 780 47' E)	640	Musi	Paravathapuram, Kachivanisingaram and Quthbullapur	50
Kanpur/Uttar Pradesh (260 28' N and 800 24' E)	1,640	Ganges	Pyondi, Sheikhpur and Motipur	193
Kolkata/West Bengal (220 34' 11" N and 880 22' 11" E)	185	Ganges	Bantala, Chowbaga, Panchannagram, Boinchitala, Durgapur, Krolberia and Bamonhata	432

Results

Estimates of Wastewater Generation

Wastewater generation across selected Class-I cities (n=498) and Class-II towns (n=410) has been assessed by institutions involved in water supply and sewage treatment (municipal corporations, state water boards, municipalities, public health engineering department, pollution control boards and other concerned agencies) (CPCB 2009). Estimates show that about 80% of water supplied is returned as wastewater, without accounting for losses due to evaporation, percolation, and groundwater recharge, i.e., the actually available volumes will differ (CPCB 2009). The results show that, with the expansion of cities over time, wastewater generation has correspondingly increased while investments in treatment capacities have varied significantly. Although several cities could show an increase in treatment capacity, the majority struggled to keep pace with urban growth as data from more than 900 Class-I cities and Class-II towns showed (Bhardwaj 2005; CPCB 2009). In 2007, total urban wastewater generation was around 38,000 mld which was three times the existing treatment capacity of about 12,000 mld (CPCB 2009). However, the survey also revealed that nearly 39% of the treatment systems were not performing to their capacity due to lack of connectivity to the sewage network systems, and/or other priorities and availability of funds of the respective municipalities. Figure 2 shows not only the share of collected wastewater across the 100 largest cities which varies from nearly 0 to 100%, but also the gap between collection and treatment.

FIGURE 2. Collected and treated wastewater across urban India.



Source: Data from NIUA, 2005.
Note: Numbers on the X axis refer to cities.

To meet the 2050 projected wastewater generation estimates of 122,000 mld for the country (Bhardwaj 2005) its strategies for wastewater treatment will need to have clear goals and investment plans in the years to come.

Pollution Abatement Activities of the Government

Three interrelated water acts address issues of pollution of water bodies in the country, and include the Water Act, 1974 (Prevention and Control of Pollution), the Water Cess Act, 1977 (Prevention and Control of Pollution) and the Environment Act, 1986 (Protection). According to the law, pollution of water bodies is prohibited; however, enforcement of regulatory measures and infrastructural capability of the government as well as of the private sector (especially the small industries) fall short of achieving the desired standards. The CPCB sets the discharge standards which are expressed as effluent discharge concentrations with parameters set as minimum acceptable standards for selected parameters such as BOD (3 mg/l), Chemical Oxygen Demand (COD) (250 mg/l) and Total Suspended Solids (100 mg/l). As part of their environment planning action for the country, the CPCB has also prepared a district-wise zoning atlas (spatial environmental planning) depicting industrial areas and industries, and environmentally sensitive areas (http://www.cpcb.nic.in/, accessed on January 24, 2013).

The river conservation plans fall under the jurisdiction of the National River Conservation Directorate (NRCD), which is under the Ministry of Environment and Forests, Government of India. It is responsible for coordinating several river conservation plans. Its main mission is to set up sewage management and treatment facilities for mitigation of pollution (domestic and industrial) through setting up of Individual or Common Effluent Treatment Plants. The GAP was one of the first activities commissioned by the directorate to address the pollution issues linked to major cities in the Ganga Basin. However, only 65% of the targeted wastewater volume was treated, and diverse issues prevented reaching the ultimate target set out by the GAP. These experiences led to the formation of the NRCD expanding the pollution abatement activities to a number of states.

Monitoring of water quality is carried out at three levels as part of the Global Environment Monitoring System, Monitoring of Indian National Aquatic Resources System and Yamuna Action Plan. Twenty eight parameters are being tested including trace metals and 22 pesticides. Currently, 1,019 river sampling stations are monitored regularly including 592 rivers and 321 wells, as well as lakes, drains, tanks and creeks. In the latest assessment, the highest BOD levels were recorded as 714 mg/ml, in the Sabarmati River in Gujarat (Table 3). Three states, namely Gujarat, Punjab and Andhra Pradesh had some of the most polluted rivers. Overall, 64% of the 1,019 control points indicated BOD levels less than 3 mg/l, 18% between 3 and 6 mg/ml and 18% over 6 mg/ml. Fecal coliform concentrations in 21% of the stations exceeded 5,000 MPN/100 ml, and 53% showed levels less than 500 MPN/100 ml. Fecal coliform concentrations were highest in certain stretches of the Yamuna River (MPN 5.2 x 106 to 3.7 x 106). The STP discharge standards for fecal coliform (MPN/100 ml) are 500 desirable and 2,500 maximum permissible, and for BOD 3 mg/l or less (CPCB 2008), a value not met in any of the river sampling points listed in Table 3.

While concerted efforts are made to monitor the water quality of large surface water bodies and groundwater, with the involvement of many ministries and institutions at state level, water quality in man-made stormwater canals and drains is not measured. The water from these drains is used for urban and peri-urban agriculture, as well as for other activities in many cities and, therefore, monitoring all types of water sources would help plan for reductions in pollution loads reaching the open waterways.

Activities related to abatement of water pollution range from simple sedimentation to more capital-intensive STPs, most of which utilize conventional technologies with activated sludge processes (ASP) and the Upflow Anaerobic Sludge Blanket being common technologies (CPCB 2009). The systems are often not operating to their full capacity and treatment is hampered due to various reasons, such as lack of trained staff and inadequate supply of spare parts. There is a growing interest in adopting new technologies for water recycling within cities among which are bank filtration (Lorenzen et al. 2010), reed beds, natural wetlands, constructed wetlands (Mittal et al. 2006) and soil aquifer treatment systems (Kumar 2009). Successful natural treatment systems are exemplified by the ECW, which have been in existence for hundreds of years, natural treatment ponds with aquatic plants in Pune, and numerous constructed wetlands in other cities of India (CPCB 2002).

TABLE 3. BOD levels of some selected rivers in India during the period 2006-2007.

River/lake	City/District	State/Union territory	BOD (mg/l)
Amalkhardi	Ankelshwar	Gujarat	714
Ghaggar	Moonak	Punjab	626
Khari	Ahmedabad	Gujarat	320
Musi	Hyderabad	Andhra Pradesh	225
Sabarmati	Ahmedabad	Gujarat	207
Kalinadi	Kannuaj	Uttar Pradesh	136
Khan	Indore	Madhya Pradesh	120
Damanganga	Kachigaon	Gujarat	112
Kalinadi	Muzzafarnagar	Uttar Pradesh	110
Saroonagar Lake	Saroonagar	Andhra Pradesh	71
Ghandigudem	Medak	Andhra Pradesh	60
Hindon	Saharanpur	Uttar Pradesh	60
Yamuna	Delhi	Delhi	59
Bhima	Pune	Maharashtra	36
Hussain Sagar	Budamaru	Andhra Pradesh	33

Source: CPCB, 2007.

Valuing Wastewater Use in Agriculture

The value of wastewater can be expressed in many ways. Wastewater is a reliable water supply for crop production (cereals and vegetables) where freshwater is scarce; high nutrient content helps reduce input costs; it provides an ideal medium, e.g., for aquaculture, and can replenish groundwater reserves. Where trees or fodder are produced, land application provides at least a low-cost, but productive, way for sanitary disposal of municipal waste. Use of wastewater for irrigation and aquaculture is a common practice in India, but is usually part of the informal sector which does not receive much recognition from the government (Buechler et al. 2002; Buechler and Mekala 2005). Assessing the economic value of sewage farming is facing many challenges (e.g., where does diluted wastewater end and polluted freshwater start?) affecting estimated areas under irrigation and related indicators (Weldesilassie et al. 2011).

With increasing urban water demands, and realization that wastewater irrigation is a common reality, the economic value of municipal wastewater is being gradually recognized. In addition, Water Boards of different municipalities started exploring the possibility of revenue generation from the by-products of wastewater treatment (CPCB 2007; WABAG 2012). In an assessment done by CPCB, for coastal Class-I cities and Class-II towns, the annual value of the N, P and K loads from a total of about 5,000 mld of wastewater was estimated at INR 1,091 million (wastewater, INR 76 million; nutrients, INR 1,015 million) (CPCB 2009), not counting the environmental damage it is causing. This computation is of course theoretical but sets an important signal towards resource recovery and environmental conservation.

With the available data for Class-I cities and Class-II towns and other studies, we attempted to estimate the area irrigable with wastewater, which can be used for farming directly from treatment plants or indirectly (wastewater discharged to rivers). When water channels were directly used for irrigation, accounting for the irrigated areas with wastewater (treated and untreated) was possible. However, when large volumes of surface water (rivers and ponds) containing wastewater were channeled and lifted for irrigation, calculating the wastewater irrigable land became more complicated, challenging also any related economic assessment. Some assumptions made in arriving at the estimates were soil types, wastewater ratio and application rate per hectare. Crop varieties were not considered due to limitations on data availability. For direct use, it was assumed that the wastewater was partially treated, and the volumes were calculated using the design capacity of the sewage channel or treatment plant. For indirect use, wastewater applied was calculated as a percentage of the water supply to the city (following Van Rooijen et al. 2005). The estimates of wastewater-irrigated area for direct use were about 6 hectares (ha) per mld, and for indirect use 39 ha per mld. The area under indirect use accounts for mixing with non-wastewater sources of irrigation. Using these volume-area relationships, the data for Class-I cities and Class-II towns indicate that the potential irrigable land can be estimated to be around 1.1 million hectares (Mha) (Table 4).

A more detailed analysis for all India and beyond is currently underway by IWMI using remote sensing (RS) and hydrological modeling. It will extend the FAO AQUASTAT database which distinguishes between treated and untreated wastewater use but, so far, considers only the direct use of collected and treated wastewater. It is suggested to build any data collection on the larger AQUASTAT data format (treated and untreated wastewater) to develop strategies for its treatment and/or appropriate use, especially for agriculture.

The format proposes a participatory method of data collection to the extent possible, so that the same terminology is used across institutions, and country and all input sources are integrated into the calculation and data management process.

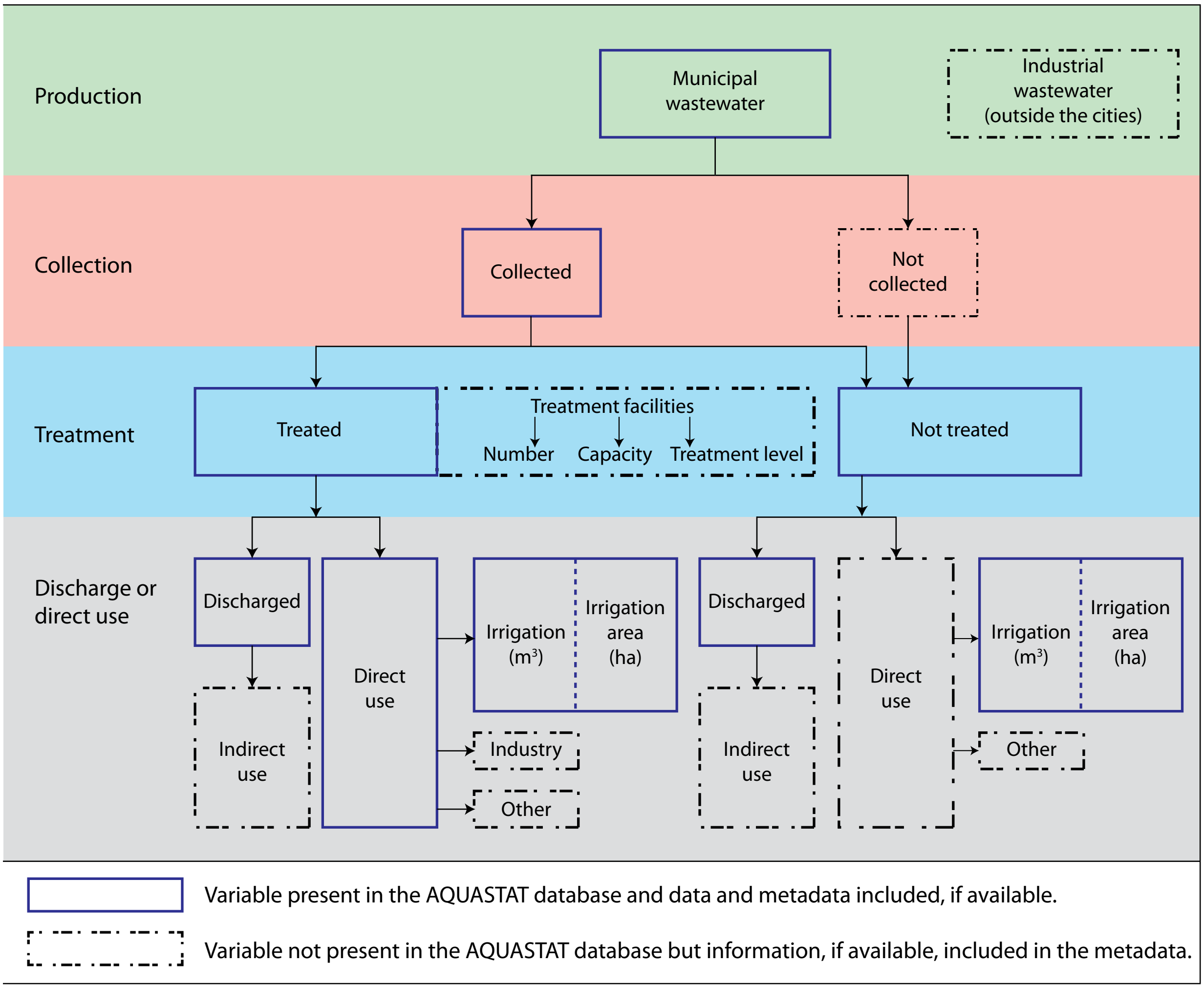
The upper part of the FAO template (Figure 3, wastewater production) could be expanded, as shown in Figure 4, to take into account the different sources of water supply for the cities, and it attempts to record the different streams of water inputs that eventually contribute to the total wastewater volume generated in a city. Together with the FAO framework, it can cover the different treatment options the cities might have, and attempt to assess the quantities discharged into the ecosystem. Water quality assessments and treatment capabilities, coupled with studies on Geographic Information Systems (GIS) (Box 1) can support an assessment, which can provide a better understanding of the potential uses and area under wastewater irrigation.

TABLE 4. Estimates on potential irrigable land with wastewater in Class-I cities and Class-II towns.

	Volume of wastewater (mld)	Ratio of direct versus indirect use	Potential irrigable land (ha)
Treatment capacity	11,787	6	70,722
Untreated	26,467	39	1,032,213

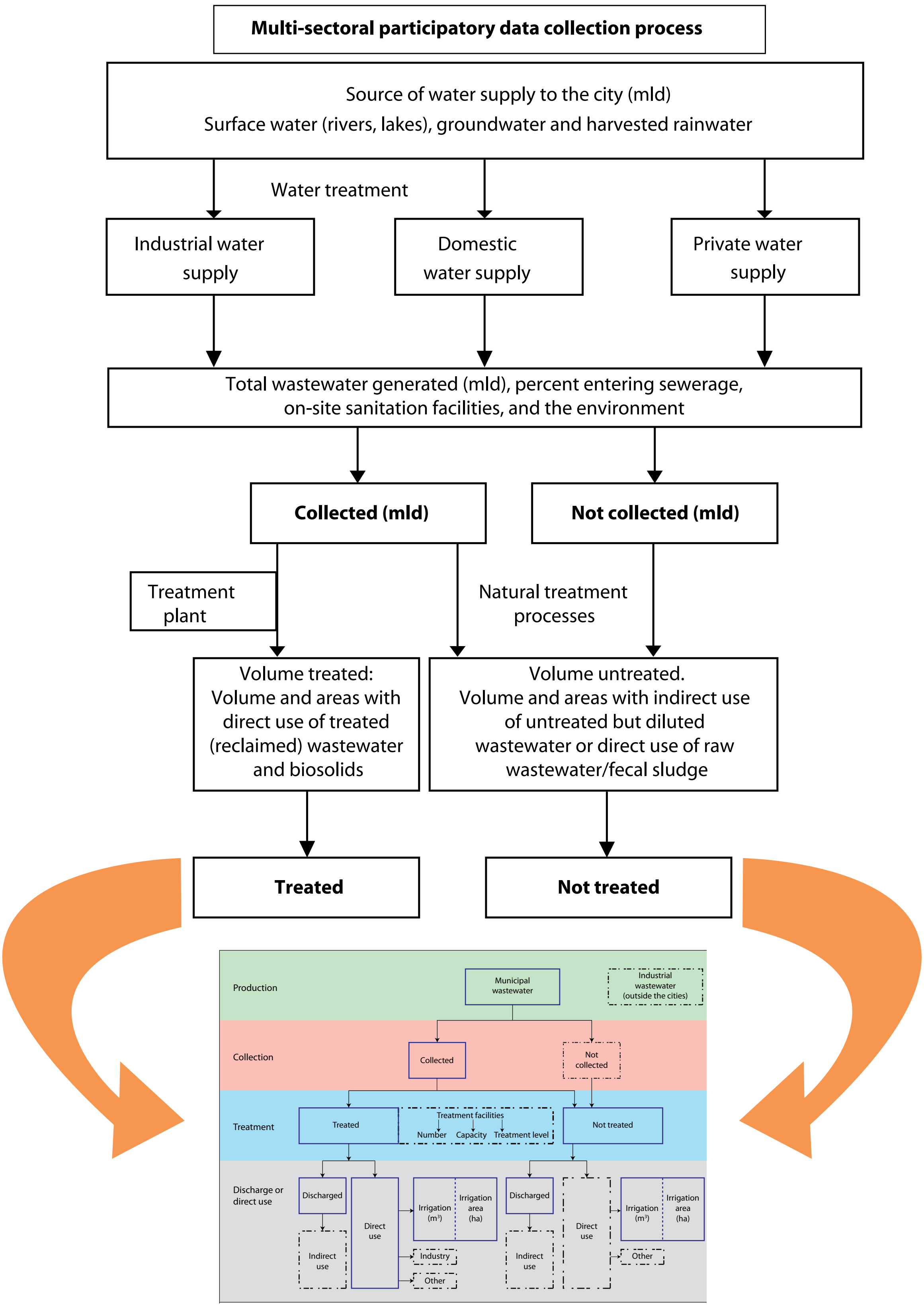
Source: Adapted from Winrock International India; Institute for Studies and Transformations; Jadavpur University. Department of Economics; Eco Friends; Spatial Decisions; Youth for Unity and Voluntary Action (YUVA), 2006.

FIGURE 3. A data collection template for assessing wastewater generation in cities based on the FAO AQUASTAT framework.



Source: Modified from Mateo-Sagasta and Salian, 2012.

FIGURE 4. Suggested data collection template for assessing wastewater generation in cities, feeding into the AQUASTAT framework (Figure 3).

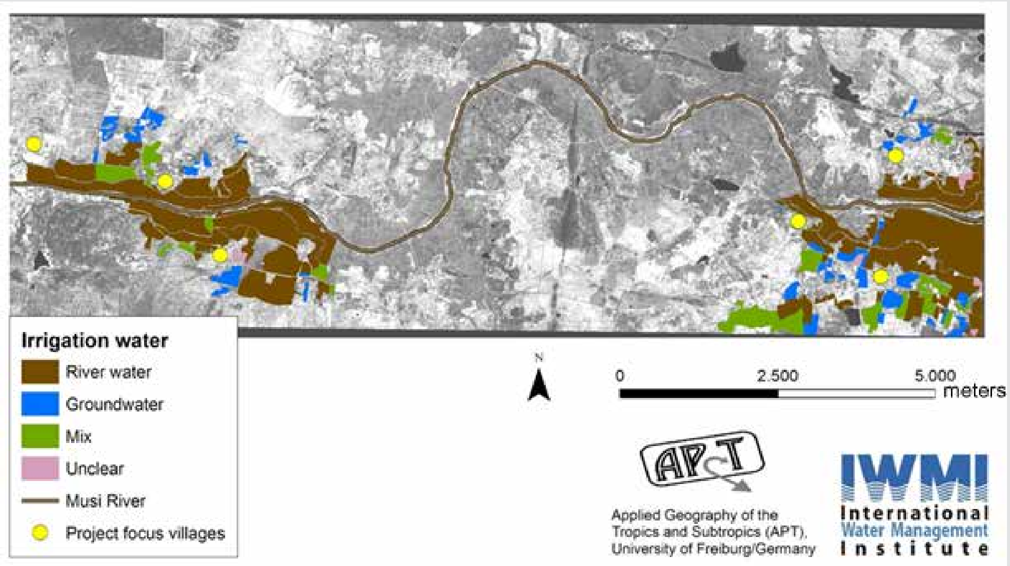


BOX 1. Use of GIS to assess the area under wastewater irrigation.

GIS-based irrigated area mapping was carried out in selected sites in Hyderabad, India, and Faisalabad, Pakistan, to assess the extent and the different sources of irrigation. The study investigated the health and food safety issues from rapidly expanding wastewater irrigation in these two locations. GIS layers of soil quality, irrigation water typology, land use patterns, water quality, prevalence of infections, and other demographic information produced a rich contextual visualization of agronomic, health, environmental and economic implications related to wastewater use in the area. While all of these individual data sets could be analyzed in their own right, additional layers of information helped link the different components of the study, bringing together different stakeholders to discuss a common issue. The example of a GIS map given in Figure 5, shows the sources and the extent of water used for irrigation in two zones (peri-urban and rural) along the banks of the Musi River, Hyderabad India. Such maps can be overlaid with other indicators like soil and water quality or disease incidence to visualize their spatial distributions and possible associations with wastewater irrigation. In particular, data on crops grown during the year in different plots, crop yield, input use including wastewater, input costs, labor days, outputs, markets and prices, etc., as well as disease incidence and treatment cost and preventive expenditure can be overlaid to estimate the economic value of water for each crop and use.

Source: Philipp Weckenbrock and Axel Drescher, University of Freiburg, Germany.

FIGURE 5. Characterization of irrigated area in two zones (peri-urban and rural) along the Musi River (Uppal to Pillaipalli), Hyderabad, India.



Sources: http://wwiap.iwmi.org/Data/Sites/9/DOCUMENTS/PDF/bmz_india_finalatlas_27oct09.pdf
http://www.freidok.uni-freiburg.de/volltexte/6960

Case Studies: In-depth Analysis

The urban wastewater challenges were investigated looking at the water supply to selected cities, wastewater generation, sanitation coverage, sewage treatment scenarios, wastewater use, water quality and perceived health impacts. Secondary and primary data together with livelihood analyses of 289, 80, 50, 193 and 432 farmers from Ahmedabad, Delhi, Hyderabad, Kanpur and Kolkata, respectively, formed the basis for the analyses. These cities were considered as a representative cross section of the country.

Drinking Water Supply: Wastewater Generation and Treatment

Current wastewater generation figures are an estimation based on the water supply to the cities. In all five cities the drinking water supply was met by surface water and groundwater sources in different proportions, with surface water being the primary source (Table 5). The data have to be used with caution as there are indications of much greater groundwater exploitation within cities, but without data to support these indications. City water supplies have increased over the years as demand has grown and water is lifted from more distant sources with the consequent estimated wastewater generation. Percentage treatment capacities varied widely between the cities, and the current treatment capacities have been increased in keeping with the increase in water supply in cities like Hyderabad (Van Rooijen et al. 2010). However, the waterways are still polluted, due to sewers ending in streams, indiscriminate disposal of non-networked wastewater drainage and industrial discharges, and also because a new treatment capacity does not imply households are already connected.

Wastewater treatment has improved in some cities like Hyderabad and Ahmedabad, but has fallen far behind the requirements in cities like Kanpur and Kolkata, which is not surprising given the rates of urbanization and decadal population growth in the cities and government development plans (Table 6). It should be noted, however, that the figures in Table 6 are continuously changing, linked to population growth, reporting and infrastructural development. Thus wastewater generation and treatment values given in different publications of the CPCB often do not match. An example is Hyderabad where about 585 mld of wastewater were generated in 2008. This exceeds the current treatment capacity by far, but with new treatment plants getting commissioned the capacity will soon be at the same level. However, this will again not be enough to catch up with the increased population at that time (Van Rooijen et al. 2010). Ahmedabad has today four STPs with a capacity to treat 633 mld, sufficient to cater to all wastewater, but infrastructural development lags behind and the plants run below capacity. Under the GAP three treatment plants were set up in Kanpur; however, even the treated water is reported not to reach the basic standards of irrigation water quality as defined by FAO (Pescod 1992). In short, it is very difficult to get reliable data, and even if there are data, they might not tell what is really on the ground.

Wastewater Use, Livelihoods and Financial Benefits

Irrigation with wastewater was practiced in all five cities, but varied in terms of area, types of crops, and the quality of water used (Table 7). The major users of wastewater in the study sites were farmers growing cereals (rice), horticultural

TABLE 5. Sources of urban water supply in the study sites.

City	Surface water (%)	Groundwater (%)
Ahmedabad*	93	7
Delhi**	86	14
Hyderabad**	99	1
Kanpur**	60	40
Kolkata*	88	12

Source: * ADB 2007; ** Municipal corporations.

TABLE 6. An overview of water supply and wastewater generation in the case study cities.

City	Sewage generation (mld)	Sewage treatment capacity (mld)	Treatment capacity (%)
Ahmedabad	488	472	96
Delhi	3,800	2,330	61
Hyderabad	426	133	31
Kanpur	417	171	41
Kolkata	706	172*	24

Sources: CPCB, 2005, 2009; Van Rooijen et al., 2010.

Note: * without wetlands.

TABLE 7. Summary of wastewater use and crops in the study sites.

Study area	Land under wastewater irrigation (ha)*	Farming households engaged in wastewater irrigation*	Quality of wastewater used for irrigation (T-treated; U-untreated†)	Type of use (direct/indirect)‡	Types of crops
Ahmedabad	33,600	NA	T+U (treated wastewater use was more; however, the treated water is getting increasingly contaminated)	Direct and indirect	Vegetables, rice, other cereals, fodder/grasses, cotton, fruit trees, ornamentals, pastures
Delhi	1,700	12,000**	T – Areas close to STPs (Keshopur, Okhla) U – Along the riverbanks and inside the riverbed	Direct	Summer - Cucurbits, eggplant, okra and coriander Winter - Spinach, mustard, cauliflower, radish and cabbage
Hyderabad	10,000	NA	T + U Treated wastewater is released to the Musi River which is used for irrigation downstream	Indirect	Para grass, rice and vegetables
Kanpur	2,500	2,447	T+U T or U wastewater is sold to farmers. Industrial water (tannery) is mixed in certain areas. Some farmers use the polluted waters of the Ganga and Pandu rivers for riverbed farming.	Direct and indirect	Wheat, rice, vegetables, mustard and flowers
Kolkata	4,887	2,500	U – All sewage channels are diverted to the ECW	Direct	Fish, paddy and vegetables

Source: Adapted from Winrock International India; Institute for Studies and Transformations; Jadavpur University. Department of Economics; Eco Friends; Spatial Decisions; Youth for Unity and Voluntary Action (YUVA), 2006.

Notes: * Estimated values; ** includes contractors as well as landless laborers; † directly from sewers or polluted river; ‡direct – when a channel specifically reaches the irrigated land; treated/untreated / indirect – when a polluted surface water body is used for irrigation; NA = data not available.

and fodder crops, aquacultural businesses (mostly in the ECW and Delhi), and to a lesser extent floriculturists. In Delhi and Kanpur, wastewater irrigation was supported by the municipalities where treated effluent was discharged into specified locations for a fee, so that the farmers could cultivate crops. In Delhi, 22 major drains and STPs (Keshopur and Okhla) provide partially treated and untreated wastewater for agriculture, and the survey revealed that 71% of market produce in Keshopur and Okhla areas was met by the crops grown in these two sites. In contrast, in Hyderabad, only 1-2% of the wastewater-grown vegetables contributed to the market, and the municipality discouraged using wastewater for agriculture (IWMI 2008; Amerasinghe et al. 2009). Over time, the farmers have observed that the quality of wastewater has deteriorated due to the mixing of domestic and industrial wastewater, and many downstream users complain that vast areas of agricultural land that previously received clean river water are now irrigated with increasingly saline water. Since there is no alternative source of water, users have adapted themselves to the situation (by changing the crops) and have continued to use the water available, irrespective of its quality. Low-cost technologies like riverbank filtration are also being tested for their relative merits (Lorenzen et al. 2010), and their wider use can be expected in the future.

In general, community reflections on the past and present uses of wastewater, and the related advantages and disadvantages were similar to those stated by wastewater farmers of many other countries, but the responses were mixed for the same location, reflecting the individual experiences (Table 8). The most common response was that wastewater provides a reliable water supply, despite concerns of water quality. In Ahmedabad and Delhi, for some, the high nutrient content boosted vegetable production (Table 9), but for others the soil fertility had declined and impacted agricultural productivity. The latter attributed it to poor water quality affecting the soils. Some used less fertilizer, and felt that it was profitable, while those who received treated wastewater noted that the soil quality is being restored gradually and the income generated was significant (Table 10). Livestock-rearing was a popular livelihood activity in the study villages, but some reported that the health of livestock was affected due to wastewater consumption. In Kanpur, income was higher among the farmers using wastewater than those who used groundwater for fodder (Table 11). In the same city, staple crops like paddy and wheat appeared to have had a better profit margin than fodder or floriculture (roses), when wastewater was used for irrigation (Table 12). In Hyderabad, over 13 types of vegetable crops were grown with wastewater to supplement the household income, especially by women farmers living in the peri-urban regions (Jacobi et al. 2009). However, the landscapes were changing with vegetable farms being gradually pushed further afield, to accommodate the new city limits. The pattern these data show is that there is no clear-cut answer for how far and where the use of wastewater (or highly polluted stream water) is perceived as an advantage or disadvantage. There is a high degree of variability between soil and crop responses and water quality (Weldesilassie et al. 2011).

The ECW ecosystem is a well-known example where wastewater is made an asset. These ecosystems support four principal resource-recovery and reuse practices namely, vegetable farms (using urban waste), wastewater-fed fishponds, paddy fields using fishpond effluent, and sewage-fed brackish water aquaculture. The wetlands cover an area of around 12,742 ha (water bodies: 4,728 ha; degraded water bodies: 1,124 ha; agricultural area: 4,960 ha; (urban waste) farming: 603 ha; and settlements: 1,327 ha) where up to 1,300 mld of wastewater are absorbed (IWMED 2004). The total area of sewage-fed fisheries is around 3,900 ha, with around 308 ha of fisheries managed by private concerns (93%), cooperatives (6%) and the State Government (less than 1%) (IWMED 2004; Kundu et al. 2005). In 1999-2000, estimated production for the ECW was 12.8 million kg of paddy, 6.9 million kg of fish and 69 million kg of vegetables (Chattopadhyay 2001), supporting a population of around 60,000. The

TABLE 8. Perceptions of farmers on wastewater use in the study villages.

City	Past use	Present	Perceptions on importance
Ahmedabad; 289 households	Clean river water was the primary source of water for farmers cultivating along the riverbanks. Horticulture was the main income-generating activity. Some cereal crops were also grown.	Presently, 90% of the land area is irrigated with wastewater for cultivating paddy, wheat and horticultural crops.	There is year-round water supply; however, the quality of water has deteriorated. The fruit harvests and crop yields have reduced over time. Agricultural cropping pattern has changed.
Delhi; 80 households	Wastewater was used for agricultural irrigation and aquaculture.	Diverse uses of wastewater are being experimented with, but the reuse pattern remains the same, which is mostly agriculture, aquaculture and industrial cooling.	Scarcity of water and the growing demand are forcing newer and more innovative uses of wastewater. At present, wastewater plays an important role in supporting local livelihoods.
Hyderabad; 50 households	River water became a perennial source of water, with the city discharges. However, the water was heavily polluted, but still used for agricultural production.	The banks of the river are the areas under cultivation. Para grass, rice and vegetables are the popular crops grown.	Year-round water supply has been an asset. Water quality has improved with a number of STPs being established.
Kanpur; 193 households	A sewage farm scheme launched by the Central Government in 1951 was effective and is being used still. The scheme was created to manage the pollution of the River Ganga and increase agricultural production in the area. This was a profitable business.	Marginal farmers are irrigating around 1,253 acres of land during both *Rabi* and *Kharif* seasons. However, the quality of the water has deteriorated, adversely affecting crop production. Agriculture still plays a dominant role in the livelihoods of people.	About 70% of the household economy is based on the crops grown with wastewater. However, deterioration of quality of wastewater has led to a decrease in both crop yields and milk production. Sewage irrigation has been subjected to criticism in the recent past as high concentrations of heavy metals and other toxicants have been detected. As a consequence, the farmers have refused to pay the fees levied for water since 2000.
Kolkata; 432 farmers	Domestic sewage has been used for aquaculture and vegetable cultivation by farmers since the 1930s. By the 1960s, 2,400 ha of aquacultural ponds had been converted to paddy fields as well.	City development has encroached on the wetlands reducing the area for aquaculture and other forms of agriculture including paddy cultivation. In the ECW, aquaculture and paddy cultivation are still popular. Garbage farming is common in the city waste-dumping yards. Floriculture using wastewater is a recent livelihood activity, and is gaining popularity.	Wastewater plays an important role in the livelihoods of people. No health problems have been reported so far. The reduction in productive land due to city expansion and private developers is becoming a concern.

Source: Adapted from Winrock International India; Institute for Studies and Transformations; Jadavpur University. Department of Economics; Eco Friends; Spatial Decisions; Youth for Unity and Voluntary Action (YUVA), 2006.

Note: 1 acre = 0.4047 ha (approx.)

TABLE 9. Income and expenditure per acre for cultivation of okra (*Abelmoschus esculentus*) during the summer season, using groundwater and treated wastewater in Delhi.

	Groundwater	Treated wastewater
Crop yield (tonnes/month)	1.5	2.5
Cost of land (lease cost/month)	3,000	3,000
Seeds	100	100
Irrigation water/month	100	Negligible
Fertilizers/month	500	200
Insecticides/month	1,000	1,500
Labor charges/month	3,000	4,500
Equipment operation and maintenance cost (INR)	100	Negligible
Total expenses/month (INR)	7,800	9,300
Total income/month (INR)*	15,000	25,000
Net Income	7,200	15,700

Source: Modified from Winrock International India; Institute for Studies and Transformations; Jadavpur University. Department of Economics; Eco Friends; Spatial Decisions; Youth for Unity and Voluntary Action (YUVA), 2006.

Notes: * Average price of okra - INR 10/kg (2005); INR 49.5 = USD 1 (2005).
Cost per month is an average for the season; 1 acre = 0.4047 ha (approx.).

TABLE 10. Income generation (INR millions) with treated wastewater from STPs in Delhi.

Area	Okhla area	Keshopur area
Villages	Jasaula, Madanpur, Khadar, Jaitpur, Ali	
Source of wastewater	Okhla STP	Keshopur STP
Type of crop	Okra	
Number of farmers	400 (80 households)	3,000 (600 households)
Area under wastewater irrigation (ha)	205	1,500
Volume of wastewater (mly)	27	200
Annual crop yield (tonnes)	17,220	90,000
Gross annual income (INR millions)	172.2	900.0
Annual expenditure (INR millions)	57.2	418.5
Net annual income (INR millions)	115.0	481.5

Source: Adapted from Winrock International India; Institute for Studies and Transformations; Jadavpur University. Department of Economics; Eco Friends; Spatial Decisions; Youth for Unity and Voluntary Action (YUVA), 2006.

Note: INR 49.5 = USD 1 (2005).

TABLE 11. Comparison of income of farmers using freshwater and wastewater for milk production in the city of Kanpur.

Production costs	Amount/animal		Rates (INR)		Total (INR)	
	FW	WW	FW	WW	FW	WW
Concentrates	5 kg	7 kg	6/kg	7.8/kg	30.00	55.00
Green fodder	15 kg	6 kg	50/quintal	50/quintal	7.50	3.00
Dry fodder (straw)	10 kg	10 kg	100/quintal	100/quintal	10.00	10.00
Mustard oil	300 ml/month	1,000 ml/month	50/liter	25/liter	0.50	0.90
Salt/gur (sugar product)	50 g/day	-	5/kg	NA	0.25	0.45
Maintenance cost/building /treatment/labor	-	-	15/day	NA	15.00	3.50
Total expenditure	-	-	-	-	63.25	72.85
Income from livestock products						
Milk (liters/day/animal)	8	10	10/liter	14/liter	80.00	140.00
Dung (kg/day/animal)	30	20	0.30	-	9.00	-
Income from calves	-	-	500 after 6 months	-	3.00	-
Gross income	-	-	-	-	92.00	140.00
Cost of production/liter	-	-	-	-	7.90	7.30
Net profit/buffalo/day	-	-	-	-	28.75	67.15

Source: Winrock International India; Institute for Studies and Transformations; Jadavpur University. Department of Economics; Eco Friends; Spatial Decisions; Youth for Unity and Voluntary Action (YUVA), 2006.

Notes: FW = Freshwater; WW = Wastewater; 1 quintal = 100 kg.

TABLE 12. Income generation in freshwater and wastewater irrigated areas in Kanpur.

Crops	Cost of cultivation (INR/ha)		Gross income (INR/ha)		Net income (INR/ha)	
	FW	WW	FW	WW	FW	WW
Rose	102,681	47,299	175,000	112,500	72,319	65,201
Fodder	19,630	5,204	35,000	7,500	15,370	2,296
Paddy	16,470	8,279	20,925	18,900	4,455	10,621
Wheat	20,941	10,287	29,200	19,500	8,259	9,213

Source: Winrock International India; Institute for Studies and Transformations; Jadavpur University. Department of Economics; Eco Friends; Spatial Decisions; Youth for Unity and Voluntary Action (YUVA), 2006.

Notes: FW = Freshwater; WW = Wastewater; INR 49.5 = USD 1 (2005).

revenue generated was impressive, especially under vegetable cultivation (Table 13). The gross revenue across paddy, vegetables and fish of INR 266 million resulted in net returns of INR 80 million (Chattopadhyay 2001). However, the revenues were not used at all to improve the sanitation service chain as those benefiting from the wastewater are not linked to those responsible for its management.

Estimates of Adverse Impacts of Wastewater When Used for Irrigation

Wastewater carries many biological and chemical agents that pose hazards and can impact environmental and human health. Wastewater-related health impacts could be direct or indirect, manifesting as short- or long-term illness episodes. Most studies tend to look at potential health risks by identifying contaminants in water rather than actual crop contamination and human exposure during farm work or consumption of contaminated food. The well-known agents of wastewater-associated health hazards (biological and chemical), routes of infection and their relative importance are listed in Bos et al., 2010. The state-level Pollution Control Boards in India have the capacity to test a range of these parameters in their routine water-quality monitoring, including physical, chemical and biological parameters such as heavy metals and a variety of pesticides and polynuclear aromatic hydrocarbons (CPCB 2008). The soil and agricultural products are not monitored routinely although they could be tested on request.

Wastewater used for agriculture in the four cities is contaminated with sewage, and hospital and industrial wastes at different degrees, and the possible health impacts will depend on the pollution load, irrigation history and level of exposure on the respective sites. The water and soil-quality studies in all four study sites (Table 14) clearly showed the presence of elements that can have potential health impacts. Ahmedabad and Kanpur have a larger number of industries than the other three cities, and the impacts were evident in the water-quality parameters.

There is plenty of evidence in the literature that particular chemical hazards have to be expected. Water, soil and grain analysis in sites close to Sabarmati River (Ahmedabad) showed elevated levels of some metals (Cd, Cr, Cu) in the river water and chromium and copper in the well water. High levels of lead were found in wheat irrigated with groundwater which was also contaminated (Table 14). Heavy metals (Cd, Pb and Zn) were a serious concern in and around Delhi, as several studies showed elevated levels (above the Indian standards under the Prevention of Food Adulteration Act) (Awasthi 2000) in commonly eaten vegetables like spinach, okra, and cauliflower (Marshall et al. 2003; Singh and Kumar 2006). In Kanpur and Delhi, the surface water and soils were contaminated with a variety of metals (Cu, Cd, Cr, Fe, Mn, Ni, Pb and Zn), discharged by small-scale industries which are not monitored stringently (Rawat et al. 2003, 2009).

However, Kaur and Rani (2006) found that in peri-urban farming lands of Delhi, bioavailability of metals like Cd, Cu, Fe, Mn, Ni, and Pd in the soils and surface water/groundwater was within permissible limits, with the exception of one or two samples showing elevated levels, and the geological, soil pH, overirrigation and leaching characteristics of metals bringing out differential

TABLE 13. Income and expenditure for one hectare of farmland in the ECW.

Crop	Expenditure (INR)	Income (INR)	Net return (INR)
Paddy	12,989	20,295	7,306
Fish	35,385	47,180	11,795
Vegetables and other crops	70,000	125,000	55,000

Source: Chattopadhyay, 2001.

Note: INR 45 = USD 1.00 (2005).

TABLE 14. Mean metal concentrations in water, soil, crops and grains near wastewater irrigated areas in Ahmedabad, Delhi and Kanpur.

City	Villages	Source	Unit	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Ahmedabad	Galiyana	River water	mg/l	0	0.02	0.5	0.2	-	-	-	0	0.1
	Sahij	River water	mg/l	-	0.02	0.5	0.3	-	-	-	0.2	0.1
	Gyaspur	River water	mg/l	0	0.01	0.9	1.6	-	-	-	0.2	0.7
Kanpur	Jajmau	Surface water	mg/l	-	0.01	0.06	0.02	6.3	0.3	0.04	0.04	0.1
Ahmedabad	Vautha	Groundwater	mg/l	0	0.01	0.6	0.2	-	-	-	0.4	0.6
Kanpur	Jajmau	Groundwater	mg/l	-	0.001	0.00	0.01	0.77	0.1	0.02	0.03	0.2
Delhi	Mundka	Groundwater	mg/l	-	0.0003	0.03	0.04	0.02	-	-	0.02	0.0
	Madanpur	Groundwater	mg/l	-	0.0009	0.07	0.06	0.01	-	-	0.02	0.0
		Irrigation quality standards	mg/l	0.1	0.01	0.1	0.2	5.0	0.2	0.2	5.0	2.0
Ahmedabad	Sahij	Soil	µg/g	0	0.15	25	19	-	-	-	0.98	37
Kanpur	Jajmau	Soil	µg/g	0	3.03	249	61	6,700	298	38	90	170
Kanpur	Jajmau	Vegetables (leafy)	µg/g	0	0	0.3	-	0.45	0.51	0.48	0.1	1.4
Ahmedabad	Vautha	Wheat	µg/g	0	0	0	0	-	-	-	2.67	0
Kanpur	Jajmau	Grains	µg/g	0	0.17	0.01	2.5	51	41	1.12	0.2	47

Source: Compiled from Winrock International India; Institute for Studies and Transformations; Jadavpur University. Department of Economics; Eco Friends; Spatial Decisions; Youth for Unity and Voluntary Action (YUVA), 2006.

Notes: mg = milligram/s; µg = microgram/s.

occurrences of metals at specific sites. This shows that the contamination can be site-specific, and containment and abatement strategies need to map areas of actual pollution for realistic action plans.

In general, data on short- and long-term illnesses due to wastewater handling were not available. Hospital-based data on wastewater-related diseases are in general difficult to separate from other exposures. Even more challenging are consumer surveys as in markets, where produce from different farms (safe irrigation water, poor-quality water) gets usually mixed. The responses to illness episodes were therefore gathered from survey questionnaires and key informant interviews of health personnel in the cities.

Responses to the questionnaire revealed that in Delhi, Kolkata and Hyderabad farmers complained of skin irritations, apart from the “smell” that caused breathing problems, but they did not consider it a major problem. Kolkata farmers were aware of the deteriorating water quality, and were taking precautionary measures to safeguard their skins when engaging in wastewater-related activities, using natural herbs and oils. Both Ahmedabad and Kanpur sites were cities with heavy industry, especially tanneries and, thus, their complaints were more pronounced, with visible ulceration, callous tissue formation, heavy skin irritations and dark finger nails. Public health concerns were raised over the high prevalence of helminth ova in commonly consumed vegetables like mint, lettuce, spinach, celery and parsley (Gupta et al. 2009). Increased risks of hookworm infections were observed in farmers (Hyderabad) engaging in sewage farming with high levels of helminth eggs (*Asacris lumbricoides*: 70 ova/l; hookworms: 76 ova/l; and *Trichuris trichura*: 4 ova/l) increasing the risk of nematode infections among wastewater farmers while further downstream of the Musi River water-related risks decreased significantly (Ensink et al. 2008). Significantly higher morbidity rates were also observed among wastewater farmers in Hyderabad compared to the morbidity rates of the control group that used groundwater for irrigation (Srinivasan and Ratna Reddy 2009). Although the communities did not complain, the health officials in the hospitals stated that dysentery/diarrhea, worm infections and skin problems were common among the communities, and a good majority did not seek treatment at government hospitals. Therefore, private practitioners and local quacks play an important role in treating these communities. As a result, these episodes never get into the overall health statistics. Epidemiological and microbiological investigations along with health economics studies are required to assess the health risks and economic costs associated with wastewater farming in the communities.

In several cases, produce grown with contaminated water and soils showed contamination with heavy metals, and worm and bacterial agents. While a risk assessment of Pb and Cd in rice and fodder grass along the Musi River did not show critical levels (Simmons et al. 2007), a study in Varanasi (Sharma et al. 2009; Singh et al. 2004) reported heavy metals (Cd, Pd and Ni) in vegetables at the production and market sites, partly however due to dust deposition. A risk assessment study in Kanpur developed a risk quotient (RQ) for selected contaminants (Cd, Cr, Cu, Fe, Mn, Ni, and Pb), taking into account the daily intake via the medium – water, food grains, vegetables, milk, etc. – in which each toxicant would be transported into the human body and compared with the acceptable daily intake to study the health impacts. Setting the positive risk at an RQ of 1.0, none of the elements exceeded values above 1, although the contaminant levels were above the permissible values for vegetables. Long exposure to heavy metals is known to cause a number of neurobehavioral disorders (fatigue, insomnia, decreased concentration, depression, irritability, and gastric, sensory and motor symptoms), and farmers exposed to wastewater and contaminated sludge had significantly higher scores for neurobehavioral functions tested, than the controls (Table 15). Urine and blood samples of residents working in the wastewater sites of Kanpur had heavy metals and pesticide residues so that long-term impacts can be expected unless exposure is minimized (Singh et al. 2004).

TABLE 15. Neurobehavioral functions of cohorts living close to STPs in Kanpur and Varanasi (control).

Functions	Kanpur	Varanasi
Fatigue	+	-
Insomnia	+	-
Decreased concentration	+++	-
Depression	++	-
Irritability	++	-
Gastric symptoms	+++	-
Sensory symptoms	++	-
Motor symptoms	+	-

Source: Singh et al., 2004.

Notes: (+) Significant at p < 0:05; (++) Significant at p < 0:01; (+++) Significant at p < 0:001; (-) nonsignificant.

Disease burdens associated with wastewater cannot be studied in isolation, as sanitation infrastructure, general hygienic behavior and socioeconomic factors contribute to the overall health status of a community. Low socioeconomic status, poor housing and lack of access to basic amenities like clean water can further confound findings. Cross-sectional and longitudinal health surveys, as well as market surveys for contamination and economic analyses are needed to assess the real health impacts of wastewater use in agriculture (Hanjra et al. 2012, Forthcoming).

The threshold values of biological as well as chemical hazards associated with wastewater use in agriculture were the foci of previous 1989 WHO guidelines while the newer guidelines adopted a more holistic approach, including a multi-barrier approach and health-based targets for reduction of health risks (WHO 2006). Risk minimization along the exposure pathway from producer to consumers of wastewater irrigated produce offers more opportunities where low-quality water is used than reliance on farm restrictions (Scheierling et al. 2010; Drechsel et al. 2010).

Discussion

This study attempted to look at the overall urban wastewater challenges in India (generation, its uses, livelihood benefits and health impacts). It shows that wastewater management in India is becoming an enormous challenge, as urbanization and economic development are outpacing the required infrastructural development. In an attempt to keep up with the demand, municipal authorities are giving high priority to accessing drinking water, to the extent that large volumes of water are being transported from long distances (150 km) that are part of the rural agricultural waterscape. With concerns over high costs of lifting water, energy prices, river pollution, impacts on groundwater and, above all, water scarcity, a renewed interest is generated in looking at wastewater as an asset. However, much needs to be done to explore its full economic potential as direct and indirect reuse of untreated wastewater dominates formal reuse by far.

Clearly, this study shows that wastewater needs to be considered as an important component of the water cycles within catchments, if meaningful water management plans are to be implemented within the country. In each landscape, water augmentation has to be considered in conjunction with different wastewater treatment strategies for multiple uses, and should be supported by public policy and social incentives. It can then potentially not only safeguard the downstream users but also provide economic opportunities for alternative uses of wastewater within cities and support the ecosystem services that constitute an integral part of all forms of life. A countrywide approach for wastewater use in agriculture could capture the diversity seen in the Indian context, and could best be done at state level, by identifying nodal agencies for systematic data collection. Indeed, all states must look at the alternative uses of wastewater for their cities, emphasizing the regional priorities, so that effective wastewater management plans can be developed to face the future with less freshwater. The ongoing dispute between states within India for freshwater as well as for wastewater-turned-freshwater shows the urgency of this matter.

Assessments of wastewater generation and treatment in the country have improved within the last 10 years although there are still many sewers ending without treatment plants in rivers as well as with treatment plants with a large enough sewer network to reach treatment capacity. The wastewater generated needs to be treated in order to protect the groundwater and ecosystems, and reduce downstream impacts where many livelihoods are supported (CPCB 2009). However, treatment levels can also be designed to meet the requirements of end users but this requires adequate discussion at locations where wastewater is to be used. If at sectoral level, categories of treatment for end use can be agreed upon, and it can be part of the municipal development plan, making effective use of wastewater generated in the cities. Moreover, if annual assessments are made at the city/state level, based on an agreed format, CPCB can perform nationwide projections more effectively, and in a timely manner. With advances made in the IT sector, India could well afford to develop an information management system that connects the entire country. However, capacity-building and the infrastructure have to be developed side by side for an overall positive outcome.

Assessments on wastewater irrigated agriculture and livelihood benefits of wastewater are complex. Estimates of potential irrigable land using simple or complex methods have been attempted (Raschid-Sally 2010; Van Rooijen et al. 2010). Using a crude method of calculation, this study found that over 1.1 Mha of land could be irrigated with wastewater generated from Class-I cities and Class-II towns across India. Where wastewater supplies for irrigation are provided through dedicated channels and infrastructure, calculation of potential irrigable land is easier than when wastewater is mixed with, and supplied via, natural waterways. This is because dilution changes the water quality, and estimations may require a different modeling approach altogether as currently underway by IWMI. More methods can be developed by using water-quality parameters, crop types and soil conditions. Modern tools like RS/GIS and more precise mapping of drainage networks can also provide better overall outcomes that can help assess the nutrient loads leaving the city. The urban planning sector which is currently embarking on GIS-based mapping of municipal areas can make land-use mapping as part of their program of work, to develop baselines, upon which future studies can be modeled. Wastewater irrigation can be a dynamic process in the peri-urban areas, and land-use patterns can change with development and socioeconomic change; therefore, assessments need to involve robust methods to capture this dynamism, spatially and temporally.

Benefits in terms of income generation from wastewater use for marginal farmers were more than evident from the case studies. For many, wastewater agriculture was a primary or secondary income source. Case studies showed that wastewater farmers spent less on inputs, and where the nutrient sources could be balanced the outcome was more positive (Delhi, Kanpur and

Kolkata) in terms of cost savings and economic returns. This was only based on agricultural production, and a more holistic economic analysis needs to be done to capture the net private benefits to the households and social benefits to the communities.

Wastewater agriculture is however not without negative externalities, and health impacts on farmers and consumers are of significant concern as reported above. From an Indian context more studies are required in the areas of wastewater irrigated agriculture, health and food safety, and health economics, specifically at the farm and consumer levels, to capture the diverse settings in which the problems exist. Risk assessment tools like Quantitative Microbial Risk Assessment (QMRA) and Quantitative Chemical Risk Assessment (QCRA) can be used to assess the potential risk, which should then be addressed through multiple barrier approaches with health-based targets for risk reduction (WHO 2006). In contrast to the African situation, in India, more emphasis needs to be placed on wastewater treatment processes that remove heavy metals, which appear to have much higher levels than in most parts of Africa (Raschid-Sally and Jayakody 2008).

This study suggests a data collection and collation template for assessing the wastewater generation and use within the country. It requires inputs from many sectors and can be further developed at sectoral level, to identify the gaps and include the required institutional capabilities. Such a template will also help strategize on treatment scenarios for respective cities together with economic aspects of wastewater treatment and reuse in India (Mekala et al. 2008a, 2008b). Further, decision makers may find it useful for developing a more holistic national approach for wastewater use in agriculture, with the advantage of feeding national data straight into international databases.

Wastewater management and treatment cannot be planned in isolation. They have to be a core part of the strategic plans for water supply and sanitation, irrigation and drainage, energy, and environmental services and other uses (World Bank 2004). Moreover, it becomes very important to consider these aspects in light of water availability for cities, and to highlight the need for continuous inter-sectoral dialogue and action plans to address the ever-increasing water demands (World Bank 2010). Integration of water resources development with water services can provide more support for agricultural water management. India being today more urban and peri-urban than rural, it is time safe wastewater use for agriculture was made a priority in its water development agenda.

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