Ensuring Health and Food Safety from Rapidly Expanding Wastewater Irrigation in South Asia

BMZ Final Report 2005 - 2008

IWMI International Water Management Institute
APT Applied Geography of the Tropics and Subtropics University of Freiburg/Germany
Federal Ministry for Economic Cooperation and Development
EPTRI
ILRI International Livestock Research Institute

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1. Name of IARC

International Water Management Institute (IWMI)

2. Project Title

Ensuring Health and Food Safety from Rapidly Expanding Wastewater Irrigation in South Asia

3. GTZ Project Number and Contract Number

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4. Reporting Period

The reporting period is June 1, 2005 to December 31, 2008. A no-cost extension was granted from June to December 2008 (GTZ letter of January 11, 2008).

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7. Project Description

This project aims to identify the risks and benefits associated with the use of wastewater in urban and peri-urban fodder and vegetable cropping systems in India and Pakistan, where wastewater is largely untreated due to lack of public finance. Two mega-cities (Faisalabad, Pakistan and Hyderabad, India, with large untreated wastewater irrigation areas have been selected a) for comparative purposes and b) to develop and promote country-specific risk mitigation options. With a particular focus on food safety, livelihoods and livestock, the research will combine field and laboratory methods and structured interactions with producers, consumers, and authorities (urban planning, public health and water management).

The **goal** of the project is to improve health and safeguard wastewater-dependent livelihoods of resource-poor urban and peri-urban farmers and consumers in developing countries. This overlaps with IWMI's mission to improve water and land resources management for food, livelihoods and nature. The project's **purpose** is to develop and promote the uptake of a set of risk mitigation options based on a comprehensive assessment of risks and benefits associated with wastewater irrigation in Hyderabad (India) and Faisalabad (Pakistan). The project will enable the uptake of the recommendations in two countries with large wastewater-irrigated areas and different political-institutional environments.

Outputs

1. Framework of actors and interactions. Social and institutional map of the multiple actors (individuals and organizations) along the chain from wastewater source to end-use.
2. GIS database of peri-urban and rural agriculture and wastewater irrigation.
3. Evaluation of human health and agronomic risks from field to consumer.
4. Economic valuation of the direct and indirect livelihood benefits as well as the health and adaptation-related costs of wastewater irrigation.
5. Comprehensive assessment of tradeoffs, risks, costs and benefits at different levels along the chain from wastewater users to consumers of produce.
6. Concrete, actionable risk mitigation recommendations (based on outputs 1-5 above).

8. Major Research Findings

The project reports on an improved methodology to identify the contamination pathways and critical points of intervention in the wastewater crop/fodder production to end-user chain. The different components of the methodology (risk assessment and identifying critical control points, analysis of actors and institutions, economic valuation and the direct and indirect livelihood benefits) are presented here with the salient findings and achievements where relevant, collating the evidence base to better support the WHO guidelines on safe use of wastewater in agriculture. These findings have been used to develop a set of risk mitigation recommendations to be forwarded to the stakeholders for necessary action.

The cities in the two countries (Pakistan and India) are heavy users of wastewater for agriculture, and the descriptions are given separately to highlight country specific achievements.

1. Framework of actors and interactions, health and agronomic risks associated with wastewater agriculture in Pakistan and India

A. Faisalabad, Pakistan

The studies were carried in two villages, namely**, Chakera** (31^{o} 28' 2.73" N / 72° 59' 51.79" E to 31° 25' 53.76"N / 73° 0' 57.82"E) and **Kehala** (31° 29' 39.84"N / 72° 57' 17.38"E to 31° 28' 21.10"N / 72° 58' 54.44"E). Farmers form Chakera used wastewater (WW) where as those of Kehala used canal/ground water (CW) for agriculture. In Chakera, 550.5 ha (883 ha) and Kehala 865.5 ha (998 ha) were under agriculture production. A total population of 14,178 (Chakera, n = 5488, 769 HH) and Kehala, n = 8690, 1222 HH) inhabited the two villages at the time of the study (2006). Both villages were situated close to the city of Faisalabad.

i. Framework of actors and institutions associated with wastewater agriculture

Several groups and organizations that have a stake in various aspects of wastewater irrigation have been identified and their interactions have been linked as given below (Figure 1). These interactions appeared to have been developed over a period of time, with water scarcity (frequency of availability) and salinity triggering the increased use of wastewater, especially in areas close to the city. While wastewater use for agriculture was not officially recognized the Water and Sanitation Agency played a pivotal role, as it levied a fee for utilizing the sewerage water.

IWMI made use of this opportunity to start-up a series of dialogues with the Water and Sanitation Agency (WASA) and related agencies (Ministry of Health, Environment Protection Department and community leaders of the villages) regarding improved management of the waste stabilization ponds (WSP) in Faisalabad, with a view to improving the water quality for irrigation, ground water quality and the quantity of urban wastewater being treated before it is returned to surface water bodies. IWMI has helped in the development of a proposal incorporating these ideas, to seek funds, and to the best of our knowledge the Institute is taking up the issue at its strategic planning meetings. IWMI on its part has adapted the same proposal and included it in another call for proposals and is awaiting its outcome (the GlobalHort).

The institutional requirements for wastewater agriculture have been highlighted at various stakeholders meetings, where positive and the negative impacts have been discussed, so that institutional reforms can be incorporated in their strategic planning for the future. Community awareness on negative impacts of wastewater use and risk mitigation methods have been disseminated through its community health providers (Lady Health Supervisors – LHS and Lady Health Workers - LHW) with the involvement of the National Program for Family Planning and Primary Health Care (NPFP&PHC). The Social and Institutional maps are included in a separate descriptive report.[12]

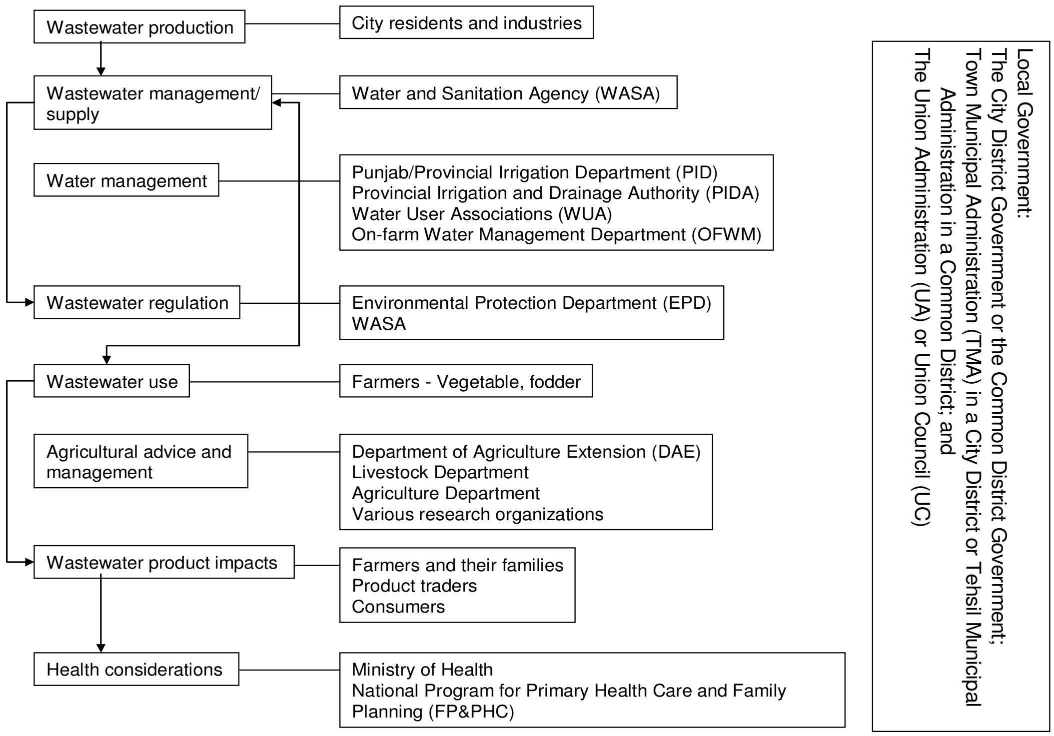

Figure 1: Actors, Institutions and interactions in the wastewater production to utilization pathway

A Stakeholder workshop was held in Pakistan for a large group of stakeholders under the leadership of the District Nazim, to share some of the methodologies and preliminary results.

ii. Evaluation of Health and Agronomic Risks Associated with Wastewater Agriculture

Health Risks

Health (Chakera, n = 2577; Kehala, n = 2153) and stool (Chakera, n = 596; Kehala, n = 638) surveys among household members, anthropometric studies of children, ground water quality studies within the homesteads revealed the following.

- The housing units comprised multiple units with extended families, sharing common kitchens. The houses were located close to each other in parallel rows with intervening roads, and therefore appeared as a clear cluster away from the fields. General hygiene within the households and the environment in both villages were poor. The health surveys revealed that latrine sharing was common (83 – 87 per cent; Chakera = 365 and Kehala = 295 households) in both villages. Many households had their own ground water supply (67 – 98 per cent). In comparison, the WW village had fewer infra structure facilities than CW village.
- Communities engaging in agriculture (main income generating activity) were 30 % and 26% in Chakera and Kehala respectively. The numbers would increase, if those who engaged in farming as a secondary activity were to be added. Overall parasite infections (protozoa and helminths) among the farming communities in both villages were similar (65 – 68 per cent) which was not expected. We expected the CW farming families to have less parasite burdens.
- Parasite species found were *Entamoeba coli, Entamoeba histolytica, Giardia lamblia, D. butschlii, Ascaris lumbricoides, Enterobius vermicularis, Trichuris trichura,* **Hook worms,** *Hymenolepis nana,*

*and Taenia saginata - a*ll parasite species also associated with poor sanitation and hygiene behaviour.

- However, hook worm infections were significantly higher among the WW farmers (16 %), indicating that contact with wastewater compounded by poor sanitation and the habit of open defecation would have contributed to these evelvated figures. The Lady Health Workers (LHSs and LHWs) were used in health education and adopting mass-scale treatment for helminths. Antihelmintic treatment had a positive and significant effect on reducing the helminth loads. Key achievement was the involvement of the NPFP &PHC for the activity, which is being continued as part of the routine treatment during primary health clinics presently (ADB outcome story).[10] Its wider application among the WW farming populations is being discussed. Continued training of the health workers on health risk reducing methods and monitoring the impacts is required.

- Protozoa infections (*Entamoeba coli, Entamoeba histolytica, Giardia lamblia)* were high in both WW and CW farming communities (31 - 42 percent) indicating poor hygiene and sanitation in both villages. Communities were advised to take treatment for these infections from pharmacies as they were not made available through the government drug delivery system.

- The water quality in the household bore wells as measured by levels of *E. coli*, total dissolved solids (TDS), electric conductivity (EC), were above the acceptable limits for drinking water, set by the WHO guidelines. The need for a drinking water supply was highlighted and brought to the notice of the authorities.

- Microbial and helminth contamination of selected vegetables (spinach, cauliflower, fenugreek and coriander) from the plots, households (storage) to the market increased progressively. This study tested the produce from the same plots through its market chain process, starting from the fields, storage in houses overnight, and the market place. The evidence points to increased contamination in the market place. This has come up as a critical point for intervention, where the health sector and water and sanitation departments will have take action.

Agronomic Risks

For selected wheat varieties, vegetable and fodder crops, soil conditions (nutrient levels, salinity, selected heavy metals), and water quality (nutrient levels, selected heavy metals) studies revealed the following.

- Across all wheat varieties soil nitrogen (N), phosphorous (P), potassium (K) and organic matter levels were significantly higher under WW as compared with CW irrigated plots. However, across all wheat varieties, long-term untreated WW irrigation resulted in ***no significant differences*** in grain yield (Dry Weight - DW), wheat straw biomass (DW), Grain: Straw Ratio, 1000 grain weight, wheat straw N-content or invitro-digestibility were observed between WW and CW irrigated plots.

- Across all wheat varieties studied, soil salinity was significantly higher under wastewater (WW) as compared with canal water (CW) irrigated plots. As a precautionary note, ECe in 20 percent of WW irrigated plots ranged from >4.0 to <6.0 dS m^{-1}. This would suggest that ECe in WW irrigated wheat fields was bordering on the critical salinity threshold (6.0 dS m^{-1}) above which reductions in yield could be expected.

- In both CW and WW irrigated plots, soil cadmium (Cd), lead (Pb) and Zinc (Zn) concentrations were below the EU Maximum Permissible (MP) levels. Further, in contrast to popular belief, the long term use of domestic WW in had ***not*** resulted in elevated levels of soil Cd, Pb and Zn as compared with the CW irrigated plots.

- For all wheat varieties across both CW and WW irrigated plots wheat straw (DW), Cd and Pb concentrations were orders of magnitude ***below*** the EC Maximum permissible levels (Directive

2002/32/EC) for these metals in feed materials. A similar trend was observed for Rabi season Egyptian clover and Kharif Season sorghum, maize and millet green fodders. Therefore, the current re-use of WW poses ***no risk*** to the fodder-milk/meat-human food chain and hence human or livestock health, with respect to these two heavy metals.

Total concentrations (FW) of Cd and Pb in the vegetables sampled were orders of magnitude below the Maximum Levels established by the Codex Committee on Food Additives and Contaminants (CCFAC). Assuming a daily leafy vegetable intake of 0.011 kg (FAO, 1994) and a body weight (BW) of 60 kg for men (aged 20-50 yr) and 50 kg for women (aged 20-50 yr) the contribution to weekly Intake of Cd and Pb derived from the consumption of leafy vegetables cultivated in Chakera is for both men and women, less than 0.5 percent of the Joint FAO/WHO Expert Committee on Food Additives (JECFA) Provisional Tolerable Weekly Intake. Consequently, the consumption of WW irrigated leafy vegetables poses negligible risk (with respect to heavy metals), to the human food chain.

iii. Economic valuation of the direct and indirect livelihood benefits as well as the health and adaptation-related costs of wastewater irrigation

- Comparison of the socio-economic characteristics of the inhabitants of both sites showed that farmers were illiterate and majority was aged 45 – 60 yr. Overall, the land under cultivation was less than 2 ha in both WW and CW sites.
- The key input costs were seeds, fertilizer, irrigation, machinery and chemicals. The overall cost of production per ha was higher in the CW site for both seasons compared with the WW site. Seasonal differences were marginal in the WW site. In the CW site, the *Rabi* season cost of production was 3 times higher than in the WW site for the same season; fertilizer, irrigation and chemical costs being the main contributory factors. In general, input costs for seeds were more in the WW site for both seasons, compared with the CW site. The difference was highest (3 times) in the Kharif season, where germination rate was observed to be lower. More chemical application was reported from the CW sites than for WW sites.
- Analysis of the yield of major crops (wheat, maize, berseem and sorghum) showed that the Gross Value of Production (GVP) in the CW site was higher as compared to the average GVP in the WW site. E.g. Average GVP for wheat was about 20 percent higher, while that of maize was about 53 percent. It is reasonable to assume that prolonged use of wastewater would have affected the soil nutrient content, which in turn would have impacted the yield of the cereal crops. A similar trend was observed in the analysis of Gross Margin.
- In assessing the benefit-cost ratio based on the gross return on the cash costs, the returns were almost double for the WW site as compared with the CW site. This is attributed to the low cost of production.
- Negative externalities associated with the different types of water use as measured by average days of illness showed that it was 19 percent more in the WW site. As a consequence the WW farmers were incurring around 18 percent more on expenses related to health. Overall, on average, the WW farmers were incurring 20 % more on day to day expenses compared to the CW counterparts.
- Poverty analysis of the different groups and classes of people carried out using Foster-Greer-Thorbecke (FGT) class of measures and household expenditure, showed that incidence of poverty was highest among the non-farmers in the CW site.
- Incidence of diseases and health expenditure ratios revealed that communities from the WW site were more susceptible to disease attack and the days of illness was about 19 percent higher, than its counterparts from the CW site.

- Econometric analysis using Cobb-Douglas production function supported the above findings.

B. Hyderabad, India

The studies were carried out in six villages along the banks of the Musi River (78^0 34' 5 - 78^0 46' 2 / 17^0 20' 3 - 17^0 24' 5). They were zoned based on the distance from the city of Hyderabad. The cluster of first three villages (1 km from city municipal boundary), Parvatapuram, Kachivanisingaram, Quthbullapur referred to as the peri-urban zone, had a combined population of 6808 from 1562 households (HH). The rural zone comprised three villages, Chinnarawirala, Maktha Anantharam and Pillaipalli having a combined population of 5081 from 1109 HH. The total area coming under cultivation within the periurban and rural zones were 492 ha 518 ha respectively (2007), with sources of water for agriculture being a mixture of surface and ground water. The use of river water (82 per cent) was higher in the periurban site, and paragrass (56 percent) was the dominant crop. Rice (97 percent) was the dominant crop in the rural zone, with farmers expanding the area of cultivation with increased use of ground water (22 percent). Lift irrigation with both sources of water using pumps was quite common, which was attributed to the subsidies offered for electricity supply. Along the stretch of the Musi river, the river water quality used for agriculture improved for selected parameters with the exception EC and total nitrogen levels. In fact, the EC levels increased significantly, in downstream sites, which have been attributed to agricultural run-off and high evapotranspiration, according to a separate study.

i. Framework of actors and institutions associated with wastewater agriculture

The actors and institutional arrangements for agriculture in the two zones were analyzed in the light of the dynamic changes observed in the city of Hyderabad during the period 2005 -2007. The Hyderabad Urban Agglomeration (HUA), which defines the new metropolis, is now over 778 km^2 having absorbed twelve new municipalities form the surrounding areas. Greater Hyderabad Municipal Corporation (GHMC) and Hyderabad Metropolitan Development Authority (HMDA; previously know as HUDA) are the new administrative institutions responsible for planning and executing its new development programs. And today, HMDA has a proposal to extend its jurisdiction over an area of 6,852 km^2, which will include all the villages that are under study. Therefore, it is clear that the areas close to the city are becoming transition zones of high activity of different types (commercial development, increased dairying, and fodder and vegetable production) and the institutional analysis thus becomes complex and hazy. A major development program for the area is the "Musi beautification program", where incremental changes are taking place in a vast area covering the Musi Banks, but affecting the livelihoods of many. At the same time Musi River conservation project aims to provide cleaner water for down stream agricultural activities, with its plans for the larger sewerage networks and sewage treatment plants (STPs), some of which are already functional and some in the pipeline.

Despite these dynamic changes, in the urban – rural continuum, the key institutions like the irrigation, agriculture and livestock institutions do appear to influence agricultural activities, directly or indirectly (Figure 2). The two study zones which come under an ancient irrigation scheme comprising a network of canals and lakes that provide water for agriculture along the banks of the river, are still serviced by these institutions by way of monitoring water releases and rehabilitation of the canals. From the community perspective, Water User Associations (USA), Primary Agricultural Credit Societies (PACS), Agricultural Marketing Committees (MAC) and Community-based Farmer Organizations engage interact for their needs and requirements. These outcomes appear to be complex and hazy without proper direction.

It was apparent that the real-estate boom impacted the agricultural enterprise, reduced land under cultivation, especially, in the peri-urban fringes. While livestock rearing in the city was banned by an act of legislature, it has continued to be a vibrant business that carried on informally in certain parts of the city, and spilled over to the peri-urban zone where fodder cultivation was predominant. Thus, in an environment of rapid urbanization, agrarian institutional re-structuring did not keep pace with new developments, often constraining activities related to peri-urban agriculture. However, it has been observed that market forces of demand and need for fresh vegetables, meat and dairy products has in a way forced agricultural diversification, especially in the peri-urban areas under study.

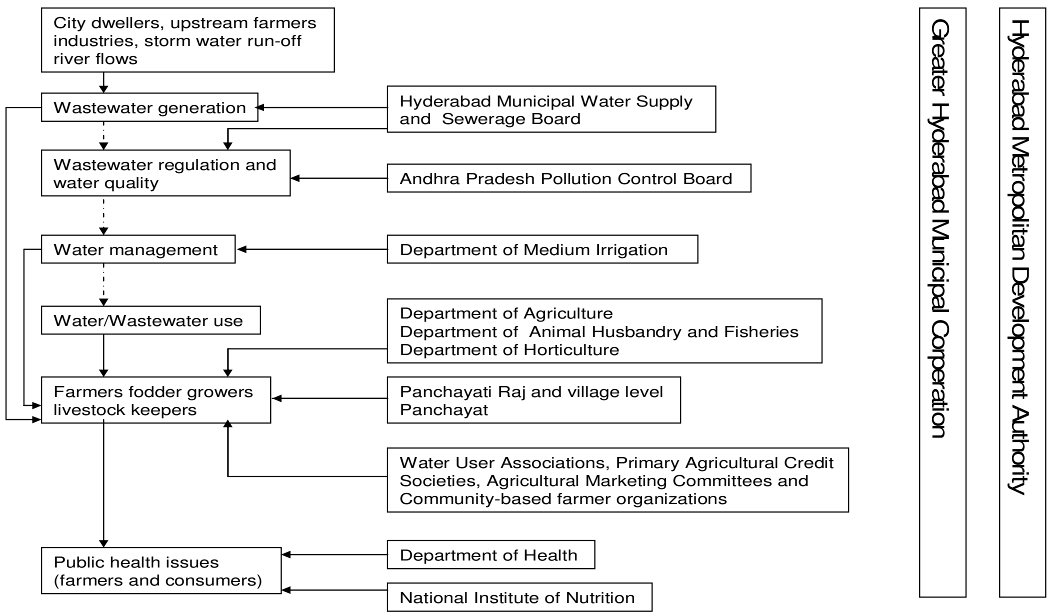

Figure 2: Actors and Institutions in the wastewater generation to utilization pathway

At the end of the study period, 45 scientists from 21 national and international organizations revisited the issues related to wastewater agriculture along the Musi River, in the light of the project findings, during a dissemination work shop. The opinions were diverse and context specific and the need for objective assessments of different studies were highlighted. The stakeholders (government) who attended the meeting was keen on having access to the different data bases, which according to them would serve as a baseline, for future planning activities.

In summary

- Availability of Wastewater proved to be a valuable resource for both paragrass and green vegetable production, which required fewer inputs, according to the periurban farmers.
- Market forces of demand and need for food (perishable vegetables, meat and dairy produce) have resulted in a diversification of agriculture from paddy to para-grass cultivation. Both vegetable and para grass production and the dairy industry reported growth.
- In an environment of rapid urbanization, agrarian institutional re-structuring has not been complementary and many factors have constrained urban and peri-urban agriculture.
- New growth and urbanization have not been conducive to traditional agricultural practices of paddy cultivation.
- Supportive policies on the formation of cooperative societies and self-help groups, access to credit and microfinance was growing.

- Institutional arrangements for providing cleaner water to down stream users are in place, but its implementation showed slow progress. By 2008, the largest Sewage Treatment Plant (STP) was in place and functioning. Increasingly, smaller STPs (20 mld) are becoming common, especially in association water bodies and new development sites, indicating a greater awareness on sustaining a cleaner environment within the city, which will have a positive impact downstream.
- What was lacking were government policies that recognize the use of wastewater (it happens in reality) and provision of more support for wastewater agriculture. In a water scarce setting, with water being lifted from far off places for domestic use, closer scrutiny and necessary action on safe use of wastewater can have economic benefits as well.

ii. Evaluation of Health and Agronomic Risks Associated with Wastewater Agriculture

An initial household listing of periurban (n=1319) and rural (n=1064) households revealed that when both primary and secondary income generating activities were considered, 50 percent and 90 percent of the population respectively, had engaged in agriculture. For health studies, comparisons were made across the periurban and rural zones, among the farming population, unless otherwise stated.

Health Risks

- Health (periurban: n = 1145, rural =1047), stool (periurban : n = 232; rural = 261) and diarrhea (periurban: n = 295; rural = 298) surveys among household members, of children, ground water quality studies within the homesteads revealed the following.
- In the periurabn zone the Individual housing units were well constructed but crowded, with the exception of one village where urbanization was felt only marginally. The houses were more spaced out in the rural setting with more garden space separating housing units. Latrine coverage in the periurabn zone was 80 percent, with 39 percent (n=164) sharing the facilities. In comparison in the rural village it was 60 percent (n=187) being shared. Open defecation was common in the rural zone and the hygiene standards were poor. There was an increasing demand for the city water supply (Krishan and Manjira) for drinking water, which was supplied to the periurban zone through special connections on the roadside. In the rural setting, most houses were dependant on groundwater which was pipe-borne to a large extent. City water supply had reached only the village of Chinnaravirala, and the other villages had to buy the water at a price from bowsers.
- The overall parasite prevalence was low across the farming populations in both periurban (8 percent) and rural sites (9 percent). Parasite species present were *Entamoeba histolytica, Giardia lamblia, Ascaris lumbricoides, Trichuris trichura,* hookworms, *Hymenolepis nana* and *Taenia saginata.*
- No hookworm positive cases were found in the sampled population in the periurban zone. Very low (3 percent) prevalence rates were reported from the rural zone. Irrigation water in the latter site was not positive for worm eggs, therefore, the infections were attributed to general sanitation conditions and high numbers of migrant labor that come to the village during the harvesting seasons.
- At least a single diarrhea episode during the last 2-3 months was recorded by the farming population in the periurban and rural sites at 38 percent (n=295) and 57 percent (n=298) respectively. Cases reported for the non-farming categories were similar, and overall poor sanitation conditions in these areas would have contributed to the illness episodes. Deworming and treatment was recommended to those who reported positive during the study. Because of low prevalence rates, no mass scale deworming was undertaken in the Indian sites.

- Microbial and helminth contamination of selected vegetables (*Amaranthus*, spinach, mint and coriander) showed that only spinach had *E. coli* levels above the permissible levels set by UK (<20 *E.coli* counts for market produce). Helminth ova posed negligible risk, for the period tested.

Agronomic risks

For selected rice, vegetables and fodder crops, soil conditions (nutrient levels, salinity, selected heavy metals), and water quality (nutrient levels, selected heavy metals) studies revealed the following.

- Across all three rice varieties soil N, P, K and organic matter levels were significantly higher under 'direct' as compared with 'lift' and control (ground water) irrigated fields. Across all three rice varieties no significant differences in straw yield or invitro-digestibility were observed between 'direct' 'lift' and control irrigated fields. However, rice grain yields were 30-40 percent lower in 'direct' as compared to 'lift' and control irrigated plots. This is in large part due to the high N-status associated with 'direct' irrigated plots.
- Across all three rice varieties and villages no significant differences were observed in soil ECe between 'lift', 'direct' or control fields. However, the high soil ECe values observed suggest that salinity induced reductions in yields are to be expected.
- 47 percent of rice field sampled had total soil Cd concentrations exceeding the EU Maximum Permissible (MP) level. Irrespective of irrigation type, all total soil Pb and Zn concentrations were significantly lower than the EU Maximum Permissible (MP) level for Pb and Zn in soils.
- Across all three rice varieties investigated straw Cd and Pb levels were orders of magnitude below the EC Maximum permissible levels (Directive 2002/32/EC) for Pb and Cd in feed materials irrespective of irrigation method or duration of wastewater use. Therefore, the current re-use of WW poses ***no risk*** to the fodder-milk/meat-human food chain and hence human or livestock health. Similarly, Cd and Pb levels in paragrass were orders of magnitude below the EC Maximum permissible levels for Pb and Cd in feed materials.
- Zinc Deficiency: Of the 64 plots tested, over 30 percent were associated with DTPA-Extractable Zn concentrations less that the critical threshold of 0.8 mg Zn kg^{-1} below which Zn deficiency symptoms would be expected in rice. This is supported by the fact that over 95 percent of the rice straw samples contained Zn concentrations of <15 mg kg^{-1} (DW) considered as a reliable indicator of Zn deficiency.
- Contrary to general perception, total concentrations (FW) of Cd and Pb in the vegetables sampled were orders of magnitude below the MLs established by CCFAC. Assuming a daily leafy vegetable intake of 0.011 kg (FAO, 1994) and a body weight (BW) of 60 kg for men (aged 20-50 yrs) and 50 kg for women (aged 20-50yrs) the contribution to Weekly Intake of Cd and Pb derived from the consumption of leafy vegetables cultivated in the peri-urban villages is for both men and women, less than 0.5 percent of the JECFA Provisional Tolerable Weekly Intake.
- Musi river irrigated rice varieties, fodder and leafy vegetables poses negligible risk to the human food chain, at the time of sampling. However, the need to monitor these parameters at regular intervals is recommended to see that these threshold values do not exceed through time.

iii. Economic valuation of the direct and indirect livelihood benefits as well as the health and adaptation-related costs of wastewater irrigation

In economic terms, wastewater use in agriculture can be considered as a positive and/or negative externality depending on its benefits or ill effects. Thus, the analysis was undertaken in a broader framework, looking at various externalities that will help understand how best a city can deal with the generation and treatment of wastewater as well as asses the benefits to the farmer who uses it.

In this analysis all six villages were compared with a control village (Vallala) that used ground water, situated away from the Musi river. In total, 471 households (WW villages – 361; Vallala – 110) were subjected to analysis. Where necessary, a further stratified analysis based on the landholdings was also carried out.

- The households surveyed in the WW using villages were socially, economically and educationally backward. More than half of the total households were landless, and among the rest, majority were either small or marginal farmers. The major income generating activity was agriculture in over 40 per cent of the households. Only 5 per cent reported dairying as their main economic activity. Besides this finding, 67 per cent of the total workforce (considerable inter village differences were noted) engaged in activities which were either directly or indirectly related to wastewater irrigation.
- The average area under paragrass cultivation (WW villages) per household was 1.34 acres[1] and ranged from 0.77 to 5.33 acres across all villages. Details of the economics of paragrass cultivation was difficult to obtained as a large number either leased out their land or engage contract labour for grass cutting. The lease rent ranged from INR 700 to 1300 per month per acre depending upon the quality of the land.
- Twenty six percent of the households sampled engaged in livestock rearing and dairying. Paragrass cultivation supported livestock activity as evidenced by the 56 per cent of paragrass cultivators owning livestock. However, there was a negative correlation between land holdings for paragrass growing, and livestock rearing, indicating that livestock rearing and dairying is a vital economic activity for the small holder. The periurban farmers had significantly more heads of cattle (4.34 per HH), than the control village, which was clearly linked to the proximity of the city markets. It was estimated that 1.33 lakh liters of milk worth over INR 16.6 lakhs have been produced per year by the 102 households who reported dairy production (WW villages). The lowest per household milk production of 650 liters per household per year was observed in the control village.
- Average productivity per acre for the two sites (*rabi* and *kharif*) for two seasons was significantly different. Wastewater irrigated villages produced 14.43 quintals per acre where as the control village reported 18.44 quintals per acre. The productivity difference was statistically significant.

  A Cobb Douglas Production function analysis, using inputs such as area under cultivation, labour, fertilizer, pesticide and seeds, showed that quality of irrigation water adversely affected outputs. It was noteworthy, that while the farmers regarded the wastewater as an asset, in terms of input costs, it was not significantly different between the wastewater and control groups.

  An analysis of input use and net returns from paddy cultivation, showed statistically significant differences with regard to the use of certain inputs. Labor costs (including family labor) and land preparation incurred the highest expense. However, the difference in the wastewater villages and the control village was not statistically different.

  Percentage of farmers using fertilizer was less in the WW (64 per cent) villages compared to the control village (90 per cent). Consequently, per acre cost of fertilizer was also higher in the control village (INR 1074 vs INR 382). Significant differences were reported for pesticide costs where WW farmers spent more on pesticides (INR 182 vs INR 70).
- Considering four major inputs for paddy production, it was observed that the net returns for the control village were significantly higher (per acre input cost – WW village: INR 11,474; control village: INR 9,806). Accordingly, the earnings per acre of paddy were INR 7,568 in the wastewater villages and INR 10,233 in the control village. Based on these values, irrespective of

[1] 1 acre=0.4048 hectares

the size of farm, the farmers in the wastewater villages incurred net losses from paddy cultivation.

However, if the input costs of family labor were to be excluded from the calculation, the paddy farming activity appeared to be profitable. The major contribution of family labor, for paddy cultivation in the WW villages is noted. The livelihood benefits to the wastewater farmer are thus very clear. Families are able to keep the cost of production low, by using family labor.

- While providing livelihood benefits, wastewater agriculture also imposed health and adaptation related costs. In the WW villages at least 50 per cent of the total households reported illnesses (fever, body aches, skin itching, stomach ailments). The estimated morbidity for per thousand population was 70 for males and 345 for females. High female morbidity was observed for the control village as well. A logit model analysis using details of variables showed that those who owned land and living in periurban areas are less likely to report morbidity, along with those who adopted protective measures such as using boiled water for consumption. However, living close to the wastewater irrigated land, ownership of livestock and being migrant labor placed some household members at risk.
- The cost of illness which includes wage loss and medical costs was not significantly different in the two sites. What was significant was the high cost of illness related expenditure for small and medium farmers followed by landless households. The cost of illness is almost equivalent to 2 to 4 days of wage loss per month for a male worker in a household or 3 to 6 days of wage income loss per month for a female worker when estimated at average wage rate of INR 90 for males and INR 60 for females in the study area. This is a substantial loss of household income for those engaging in agriculture.

2. GIS studies in wastewater irrigated areas in Pakistan and India

- A large GIS database was created for each of the project locations in India and Pakistan. The individual layers were based on QuickBird satellite images purchased in 2006 (base maps). A semi-supervised classification of the satellite image in combination with "ground truthing" in the research area (for land use/land cover classification) formed the basis for analysis. Extensive field mapping of irrigation infrastructure, irrigation water types used, village landmarks, etc. were presented as maps for different discussions.
- Further, GIS was used as a tool to bring together information collected from the different studies (health, agronomy, demography and socioeconomic). In particular, the spatial orientation of the information collected was very useful in the visualisation and understanding the major trends in wastewater agriculture, distribution of irrigation types and its implications for livelihoods.
- A GIS manual was developed providing step-by-step methods on setting up a GIS data base in interdisciplinary studies. It comprises, information on how to set up a GIS database, with field mapping exercises (with ground truthing) in interdisciplinary settings, instructions on how to order, process and analyse satellite images, detailed instructions on technical tasks like setting GPS points and transferring into a GIS data bases. This now available in the internet.
- A GIS database comprising GIS data and maps was produced for sharing and dissemination (on DVD) among the relevant institutions in India. The manual accompanies this data base which gives instructions on how GIS can be used as a tool for depicting the spatial orientation of information collected for enhanced visualization.
- Key findings of the project was also summarised in the form of an atlas, and was presented at the final dissemination workshop in India. The atlas for Pakistan is under preparation. The final workshop was not held due to the political unrest and security issues in the country that prevailed at the time. .

- Data collected from the different groups (health, agronomy and socioeconomic studies) were presented in a manner that highlighted the linkages between the findings from the different disciplines to better understand the upstream and downstream effects of wastewater agriculture. This provided a good base for critical analysis and discussion.
- Six interns from Germany and Austria benefited from the GIS exercise. All interns spent two to four months in India and Pakistan at different stages of the project which was mutually beneficial. The training included field mapping, questionnaire administration, and data processing methods. The GIS data base was strengthened throughout with their contributions.
- GPS training was given to members of other project groups, more than 20 Indian students who were involved in the project directly or indirectly, and the research staff involved in the project in both countries. The GIS manual was field tested during the process.
- As part of knowledge-dissemination, maps were produced and handed over to village administrative representatives in Faisalabad as well as in India.
- *Some of the lessons learned during the GIS studies were:*

  A rapid assessment of the area under study by quick "ground truthing" activities that gives a snap shot of the features at a given point in time was necessary prior to purchasing an image, so as to ensure the coverage of the area under study. Studies can be aided by the freely available Google Earth images which allow good visual interpretations, especially, if remote sensing analysis is not required. Land-use patterns tend to change and this dynamism has to be captured by frequent observations during the length of the project period. It is advisable to give an overview of the usefulness of GIS studies, and how the primary data bases should be compiled to all team members at the outset. This will aid in the easy compilation of GIS data across the disciplines. Setting up a functioning line of communication at all times, where process and progress documentation is achieved is vital. A discussion forum in the internet and a person dedicated to lead the process and for the purpose of keeping it alive and vibrant is a must.

Recommendations

These are made based on the reality that wastewater farming is occurring despite the negative perspectives on wastewater use in agriculture. The usage of wastewater in many cases is due to the fact that farmers are experiencing water scarcity or not having access to cleaner sources of water. Therefore, the recommendations are aimed at looking for opportunities on a case by case basis, with the support of the decision makers to develop win-win situations.

i. Formation of a platform for dialogue with key decision makers from the different sectors (health, Livestock and Animal Husbandry, irrigation, water and sanitation, city administration, research institutes universities and farmers) in the respective countries. Preparation of an agenda that addresses life cycle assessment of wastewater generation - Make realistic assessment of wastewater irrigated areas, crops grown, degrees and of pollution in soil water and crops. Assessment of suitable treatment options, suitable crop selection, safe practices on-farm and off-farm as per the ground situation and public health aspects in vegetable markets.

ii. Design interventions based on #1 that support the livelihoods of farmers who depend on wastewater.

iii. For the present (India) promote paragrass cultivation in areas where the water is not suitable for agriculture (after soil and water testing).

iv. Provide necessary extension services to support the farmers; paddy farmers - India, and all types of WW farmers –Pakistan, to manage nutrient balances in the soils. Test out new varieties of different crops that can be grown in wastewater with the support of the extension services. In general, equip the agricultural extension services with knowledge and skills on how to deal with wastewater agriculture, accepting the fact that it is a reality.

v. Develop integrated programs with the livestock sector so that animal health and zoonotic infections and food chain contamination via animals can be addressed in a holistic manner.

vi. Rehabilitate the Waste Stabilization Ponds (Pakistan), so that farmers could have better quality water for agriculture, which will reduce health risks well.

vii. Health and agriculture departments of both countries should have special training and awareness programs on safe practices to be adopted in wastewater agriculture. Clinics for regular deworming and regular health assessments of such communities.

viii. Form a public health forum to assess and adopt safe practices in market places where vegetables are sold, to minimize health risks.

ix. Develop good GIS data bases on productive uses of wastewater for better visualization and exchange of ideas and interventions.

x. Develop programs to bring in the cohesiveness among farmers on emerging issues such as changes associated with city development. Strengthen the micro-credit groups linked to wastewater agriculture.

xi. Develop and implement policies (platform members) and regulations based on evidence from the ground, to safeguard the lives of farmers and consumers alike, guided by the WHO guidelines for safe use of wastewater in irrigated agriculture, and support the livelihoods of persons engaging in wastewater agriculture.

Auto-evaluation

Most of the activities planned were achieved, with the no-cost extension granted. Delays in activities were due to unforeseen events, such as rapid staff turn over at all levels, and political unrest in Pakistan. As such, data collection and analysis were delayed, and therefore, the publications as well. Several publications are in the pipeline and these will be completed later this year and through next year.

9. Assessment of Research Findings

Overall, the institutional capacities of the research institute, collaborating NARS and German partners were enhanced and collaborative partnerships were strengthened, during the three year period. In the ensuing interactions the importance of inter-sectoral dialogue and action, especially among the key players (Departments of health, water and sanitation, irrigation and agriculture and, farmers), to ensure health and food safety were revealed. During the project period, it was possible to form a large net work of actors and institutions, to take up further challenges and research studies in this area of work. Newer proposals were formulated with partners, to address some of the research gaps that were realized at the end of this study (GlobalHort).

The evidence base provided through the project findings was useful in convincing the stakeholders that the dialogue on wastewater generation and its re-use for food production should be a continuing one that leads to interventions. In this regard, it was made clear that the inter-sectoral institutional platforms are required to assess and address the dynamic changes that take place in the urban/periurban fringes and its impact on agriculture down stream. A good decision support system to safeguard the livelihoods of WW farmers and also to ensure safe production of food crops can be a positive outcome. For this, it was stressed that the commitment of the relevant stakeholders and the involvement of the decision makers have to be ensured.

GIS studies were an integral part of the project providing the useful tools to capture the trends and dynamic changes, in the different components of the project. Such tools can become part of institutional activities strengthening their capacity the capture these changes to take action in a speedy manner. The manual that was produced could be used by any one as it provides the methodologies in a simple user-friendly manner. Together with this there are a number of other research products that can be used by different actors.

Pakistan

The quality of the wastewater used for agriculture was different in the selected sites in Pakistan and India. In Pakistan, the farmers were forced to use wastewater in areas where water is scarce and saline. In the study village, it was seen that the sewer lines were being tapped directly to supply the water for agriculture and even a fee as levied by the Water and Sanitation Agency.

In the city of Faisalabad, <10 percent of wastewater is directed at the cities sole Waste Stabilization Pond (WSP). Of this 68 percent is utilized untreated for agricultural production generating over 1800 and 1782 t yr^{-1} of wheat grain and wheat straw (DW) from a cultivated area of only 374 ha. The remaining >90% of wastewater generated in Faisalabad remains un-utilized. The results indicate that if effectively monitored and managed appropriately the contribution of wastewater re-use to the achievement of MDGs 1 and 7 could be significant.

The stakeholder meeting that was held in 2007, helped to bring the stakeholders together in a common platform, to share some of the preliminary results generated. The fact that the leadership was given by the District Nazim, who is the head of the administration in the city of Faisalabad was a positive outcome. The meeting stimulated relevant stakeholders to work more closely with the project partners and also look for funds to improve the basic services in the WW village, in particular to rehabilitate the WSP, which had gone to disrepair with time. The findings of the project contributed directly to a dialogue between the Water and Sanitation Agency (WASA) and IWMI regarding improved management of the WSP in Faisalabad to improve water quality for irrigation, ground water quality and the quantity of urban wastewater being treated before it is returned to surface water bodies. The proposal has not yet been funded but has been adapted and included in a proposal for the GlobalHort.

The Institutional interviews identified a number of areas in which agricultural extension services, irrigation provision and wastewater management could be improved to increase the safety and livelihoods benefits of wastewater agriculture.

The information sharing meetings held in both villages revealed that people were keener on the irrigation and domestic water supplies, but not aware of the environmental sanitation aspects that was affecting their health directly. Involvement of the department of health enabled the institutionalization of WW related risk mitigation methods where Lady Health Workers were trained and mass-scale worm treatment effectively administered. Application of this model to other WW using systems is expected.

India

In India, the use of wastewater for agriculture takes place in the banks of Musi River. An estimated 1000 mld of wastewater generated from the city reaches the river, making available the water for agriculture year round. However, starting from the city center up to 30 – 40 km downstream, the water quality (some key elements) is affected, and farmers continue to grow paddy rice (downstream) having no other supply of water.

Upstream water quality (city generated) has influenced the shift from rice to paragrass cultivation, combined with the high demand for paragrass for a growing dairy industry. At present, given the water quality, paragrass cultivation appears to be the best choice for good economic returns.

However, land holdings are fast disappearing engulfed by an expanding city, and it is likely that fodder cultivation can spread downstream to meet these demands. The farmers in the rural zone however, are paddy cultivators as the distance to the city is prohibitive to engage in this activity. From the economic evaluation it is evident that the net outputs of paddy cultivation are impacted by the use of wastewater. In a concurrent agronomic study it was also shown that the yields from "lift irrigated" land (therefore, cultivated more recently), had yields comparable to ground water irrigated lands. Therefore, these farmers will need the expert advice and support of the agriculture extension officers, to remedy the soil nutrient balances affected by long-term impacts of WW irrigation.

The analysis of economic valuation overall indicates that wastewater supports livelihoods of landowning farmers who are mostly small and marginal farmers and agricultural laborers directly and indirectly of those engaged as vendors and transporters of wastewater grown produce, suppliers of inputs for agricultural activities etc. Paddy yields are significantly lower in the villages falling under wastewater irrigation when compared to the control village. When the imputed cost of family labor is included in the cost of cultivation, it is seen that paddy cultivation is not an economically viable option. However, its importance in labor absorption and therefore providing livelihoods to small and marginal farmers as well as agricultural laborers is considerable. The study points out to the need to make measures to make paddy cultivation economically viable while making use of the nutrients contained in the water.

Institutional set up is both promoting and prohibitive towards urban/periurabn agriculture due to the expanding city limits. While the supply of water for irrigation to the rural farmers is taken care of through the Water Users Associations, there is limited interest in the quality of water supplied and its impacts. The organizational capacity of farmers appears to be low, to address issues like water quality and health risk mitigation. Here in lies an area for future studies.

Where possible the farmers have been made aware of the study findings; that the source of water is contaminated, but at present the levels of contamination in the food (rice and leafy vegetables) and fodder crops are negligible. However, the situation can change with upstream events, and therefore, close monitoring is necessary to capture events that take place upstream. It was also highlighted that the biological and chemical contaminants tested only for selected elements and short-term illnesses, due to the time frame of the project. Therefore, more long-term studies are required to capture the long-term health effects.

With the evidence base generated on the health and agronomic risks, and knowledge and skills imparted (participants from universities), universities and research institutes can undertake more holistic studies to study the future trends. Curricula can include such current topics that generate an interest among the younger generation. It will be very interesting to observe the impacts of the two large projects namely, "Musi River Conservation" and "Musi River beautification" that are being implemented, albeit slowly.

Finally, at present there are no policies or regulations linked to wastewater use in agriculture for both countries. The present evidence base affords opportunities to draft recommendations (see above) that can be converted into policies at a later date. Coupled with other instruments like, regulations, safety standards as stated in the WHO guidelines, wastewater treatment options, and information and education programs, wastewater can be put to better use in the future.

10. Know-How Transfer

In general, the findings on the institutional interactions, economic valuation and wastewater contamination pathways (agronomic and health) have been shared with the stakeholders and farmers in both countries at different platforms and stakeholder meetings. The project findings have been received well and recognized as a valuable evidence base for decision making and necessary action. Training opportunities have been provided for many research staff in partner institutions, where the research methodologies and other research products have been shared. What needs to be done by each country is the preparation of a stakeholder action plan, to implement some of the interventions that have been recommended.

In general, on the agronomic front (apart from the key findings given above), the recommendation is to maintain systematic monitoring of water, soil and crop quality, as these are parameters that are likely to change with time. In the market chain of vegetable production, vegetable markets were a major point of contamination that required intervention in both countries. Therefore, putting in place a monitoring system will help pick the changes early, so that remedial action could be planned on time. This can be achieved through a sustainable institutional framework that looks after the infrastructure at market places, and social and health aspects of the communities.

On the health front, the recommendations have been imparted to the vertical and horizontal health systems. IWMI established a collaborative link with the Pakistan's National Program for Family Planning and Primary Health Care (NPFP&PHC) which comes under the Ministry of Health. The NPFP&PHC which comes under the jurisdiction of the federal government, is aimed at delivering basic health services to the rural poor. The project utilized the community-based approach where by key staff [Lady Health Supervisors (LHSs) and Lady Health Workers (LHWs)] are trained from the communities, to address deliver the key findings and set of health risk mitigation methods, especially those engaging in WW agriculture. It was seen that the LHSs and LHWs strategically positioned for dissemination of knowledge and skills among community members. The right leadership of the Provincial and District Coordinators of the NPFP&PHC the lady LHSs and LHWs workers carry out specific activities designed jointly with IWMI. The results of the activities are shared with the higher authorities of the NPFP&PHC as well as the members of the community at the end of each activity. In India, the direct health impacts due to wastewater were low, how ever such information was shared with the Institute of Preventive Medicine, the main institute identified for collaboration.

The methodologies used in this project (used in Pakistan) have been adapted and used in the WASPA project. Some of the findings, in terms of options for improved management, have already been tried in the WASPA project and are being written into current project proposals. For example, the BMZ project identified major gaps in the content of agricultural extension materials and the forms of their delivery. Efforts have therefore been made to develop materials that specifically relate to wastewater use problems and to reach urban and peri-urban farmers, who are often neglected by extension departments.

In Hyderabad, High soil pH in the study are (>pH 8.0) and high P-status seriously reduces Zn bio-availability. It is recommended that farmers apply supplemental Zn-fertilizer at critical growth stages to alleviate the inherent Zn deficiency of these soils. This needs to be transferred to the farmers and Department of Agriculture Extension Officers.

All products generated are in the public domain and can be accessed by the scientific community. The findings will be disseminated more widely in the coming months, and the project team has several papers in preparation and some have already been submitted to journals for review.

11. Training

Training and capacity building was an on-going process and occurred in all the components at different levels and intensities. GIS and Health studies trained a large number of people, as these areas required man-power in the field. Livelihood, agronomic economic studies offered training to a lesser degree.

Over 6 members of the Pakistan team, from the University of Agriculture, Faisalabad, have been trained in participatory rural appraisal techniques (PRA) including focus group discussions, venn diagrams, community mapping and household interviews. They have also learned about data management and analysis. Similar exercises were conducted in India as well. Over 40 postgraduate students were trained in the administration of household questionnaires on health, and later used to administer the health questionnaires. Nearly 20 LHSs and LHWs were trained systematically, to collect health information from participants, distribute medication, and conduct awareness programs on adoption of self protection measures during wastewater use and good hygiene practices. Several research staff (IPH, Faisalabad and local team) were also trained on some of the water quality testing methods and faecal examination of stool samples.

In India, over 30 university students were trained to carry out the health questionnaires. Several research staff at EPTRI and IPM were trained on the techniques used for health studies. Throughout the study, institutional staff and German students were offered opportunities to strengthen their skills on GIS. Some were able to visit both countries. The local trainers from partner institutes in India were unable to provide training to their counterparts in Pakistan, due to visa restrictions.

12. Lessons Learned

The two country study was a great opportunity for partners from three different countries to meet and discuss the issues on health and food safety associated with wastewater agriculture. Having partners with different competencies added value to the project. Holistic and multi-dimensional discussions helped to understand the complex interactions among the actors and institutions in the wastewater irrigation to crop production pathway. However, bringing all partners together from both countries were not always possible, due to different commitments and time schedules in their respective institutions. More effort should be made to use other forms of communication to keep the connectivity among the country partners, so that experiences can be shared for capacity and skill building.

Some of the learning experiences in one country could be easily transferred, if good working relationships are established. There could have been more exchange visits at all levels, to strengthen the cohesion among investigators. While this would have been beneficial, in some instances there were visa constraints for some partners that made such visits prohibitive, which was not very helpful. This can lead to demotivation.

A rapid turn over of key staff members slowed down some components of the project. Political unrest in Pakistan compounded the problem. This had a direct impact on the activities, delayed data gathering on the ground and carrying out tests in the field. A no cost extension was beneficial to complete the tasks in the field, but has delayed the outputs. Some publications have been made, but several are in the pipeline and will be published later this year or early next year.

The project outputs have been planned in anticipation of collecting ground level data in quick succession. However, this was not achievable at the expected rate. Therefore, not all outputs were achievable at the given target dates. A lesser number of targets spread out at a different time interval more suited to the ground situation in any given country would have been more appropriate.

Buy-in of local stakeholders at the outset is beneficial. When interventions are planned, it is easier to adopt, if the key stakeholders have been part of the program planning from the beginning. It gives them a sense of ownership of the product, and is in the best position to implement interventions.

13. Future Research Needs

Changes in water availability for all types of uses are evident from many research studies. With the expected reduction in ‘fresh’ water resources available for agriculture in arid and semi-arid countries through the re-allocation of water resources to urban centres and industry, the re-use of wastewater will, be unavoidable. There is still a reluctance to promote wastewater for agriculture in both countries though it is a reality. Therefore, as a first step, there needs to be more dialogue on this issue with stakeholders in order to convince governments to take an active interest in making it an asset.

Pre-emptive research needs to be undertaken to optimize the potential for WW re-use in production systems that can fully utilize the nutrient loads associated with treated or untreated domestic wastewater, act as 'barriers' to potential human and livestock health risks and provide sustainable livelihoods to resource poor farmers. These need to be site and water quality specific solutions and include cereals, fodders, oil seeds and biofuels. If managed appropriately to minimize potential impacts on human and livestock health, soil quality and groundwater resources the contribution of wastewater re-use to food and livelihood security could be significant.

In both countries, more research can be focused on institutional aspects. While actors and interactions have been identified, and recommendations have been discussed at a final workshop, its implementation now requires an action plan. Developing a multi- institutional framework that can discuss these issues in a sustainable manner needs further thought and action. It could be towards innovative institutional reforms, through systematic approaches that can identify synergies that exist among the institutions, some of which have been identified during this project. This would bring about better coordination, reduce competition and avoid duplication of efforts while every one is focusing on a common issue/s. is required.

From an economic perspective there are several unanswered questions on the use of wastewater for irrigation and its various impacts. While the study attempted to explain the differential yields of paddy due to quality difference in the irrigation water, it has not been able to assess the dose response relationship. In other words, it has not answered what is the agricultural impact of wastewater at different water quality levels. What are the main water quality parameters and their values at which it impacts agricultural production, productivity and farmers profitability? This is important to suggest upto what level the wastewater should be treated to yield optimal benefits. Apart from this the study has also not been able to segregate long terms versus short term effects. The analysis of livestock and paragrass cultivation also leaves back some unanswered questions. Is the proximity to the city market that makes dairying an important livelihood activity or is it because of the availability of paragrass grown with wastewater that makes livestock an important livelihood activity? More research needs to be carried out before recommending paragrass cultivation and dairying as a recommendable and permissible activity using wastewater. Similar is the case with health analysis. While the study finds out that there are higher morbidity levels in the wastewater irrigated villages, it has not been able to establish the cause and effect relationship. The relationship between common illnesses like fever, cold headache etc with wastewater use could not be clearly established though the fact is that illness has resulted in significant cost of illness. Like in the case of agriculture, it has also not been able to analyze the long term health consequences of wastewater use. This apart, the report does not identify the level or extent of wastewater treatment required and its costs and juxtapose it with the direct and indirect benefits and costs of wastewater irrigation.

Impacts of climate change and adaptation strategies for livelihoods dependent of wastewater agriculture, is another interesting area for future studies.

14. Publications

Conference proceedings, abstracts, thesis and journal articles

1. Jacobi J, AW Drescher, PH Amerasinghe, P Weckenbrock, 2009. Agricultural Biodiversity Strengthening Livelihoods in Periurban Hyderabad, India. In: Urban Agriculture Magazine no 22 - Building Resilient Cities pp. 45-47

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4. Srinivasan JT and V Ratna Reddy 2009. Economic valuation of the direct and indirect livelihood benefits as well as the health and adaptation related costs of wastewater irrigation. Report.

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7. Amerasinghe P, P Weckenbrock, R Simmons, S Acharya, A Drescher and M Blummel, 2008. An Atlas of Water Quality, Health and Agronomic Risks and Benefits Associated with "Wastewater" Irrigated Agriculture: A Study from the Banks of the Musi River, India.

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9. Evans, AEV, W Ahmed, T Mahmood, S Irum and S Mahmood, 2008. Agricultural Income and Expenditure of Wastewater and Non-wastewater Farmers in Faisalabad, Pakistan. Project report. (Currently being revised into a journal article).

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14. Chapligin B, 2007. Assessment of the hydro chemical ground water status and its relation to an integrated urban water system model based on an urban slum and rural area in Hyderabad, India. Diploma Thesis. Geochemical Institute of the Faculty of Civil Engineering Geosciences and Environmental Sciences.

15. CD-ROM of Presentations made at the Stakeholder Workshop towards Actionable Interventions on the project "Ensuring Health and Food Security in Rapidly Expanding Wastewater Irrigation in South Asia" *January 25 -26, 2007,* Serena Hotel, Faisalabad.

16. Chelluru RR, AA Khan, RW Simmonsand M Blümmel, 2006. Effect of wastewater irrigation application technique on yield and quality of rice straw. . In (Eds Pattanaik AK, Narayan Dutta and Verma AK) "Strengthening Animal Nutrition Research for Food Security, Environment Protection and Poverty Alleviation: Abstract Papers." Proceedings of the VIth Animal Nutrition Association Biennial Conference, Jammu, India, September 15-17th 2006, p 154-155.

Student Reports

17. Jacobi J, 2007. Internship Report 1st of August 2007 – 1st of October 2007

18. Suchenwirth L, 2007. Internship Report on BMZ Project "Ensuring Health and Food Safety from Rapidly Expanding Wastewater Irrigation in South Asia" 11th of September 2007 – 20th of December 2007.

19. Gayer M, 2006. Internship Report on the BMZ project of Ensuring Health and Food Safety from Rapidly Expanding Wastewater Irrigation in South Asia 16th September to 6th December 2006

20. Hofko S, 2006. Internship Report 16th September – 30th November 2006

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23. Weckenbrock P and A Drescher, 2009. Higher Yields with Wastewater Irrigation in Periurban Farming near Faisalabad, Pakistan (Poster). In_formalität und Stadt – globale Trends, lokale Dynamiken. June 5 - 7, 2009, Innsbruck, Austria, http://www.uibk.ac.at/geographie/agef/veranstaltungen/stadt/index.html

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25. Weckenbrock P, A Drescher, P Amerasinghe and R Simmons, 2008. Wastewater irrigation and crop diversity in Pakistan. Water for Development; Prospects for integrated water resources management. North South Center; Research for Development Annual Conference June 2008. (poster) http://www.northsouth.ethz.ch/news/past_events/ann_conf_08/posters

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Audio productions

1. BBC World Service radio production – Urban agriculture in Hyderabad - 'One Planet' series, 24th July 08. Produced by Andrew Luck-Backer. http://www.bbc.co.uk/worldservice/programmes/one_planet.shtml

2. BBC World Service radio production – Science in Action Series – 23rd August 08. Produced by Andrew Luck-Backer http://www.bbc.co.uk/worldservice/programmes/science_in_action.shtml

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