Case Study in Pakistan: Water Quality and Health Impacts of Domestic Use of Irrigation Water

Report compiled by Peter K. Jensen, IWMI HQ, Sri Lanka

BACKGROUND AND RATIONALE

The domestic users of irrigation water currently face two simultaneous problems: a depleting quantity and quality of their drinking water resources. Not only do national and international policies encourage irrigation departments to diminish the available water in irrigation systems to optimize yield from the national water resources, but the available irrigation water is of an inferior quality as a result of intensified use and reuse upstream in the rivers and catchment areas.

A key factor is global urbanization, which causes an enhanced demand for water allocations to cities and industries, thereby increasing competition between the urban and rural sectors. Agriculture and thereby the domestic users in the irrigated areas are bound to lose the battle for the scarce global freshwater resources owing to a lower economic productivity of water (value per drop) than the industry. According to the United Nations Environmental Program (UNEP), irrigation currently accounts for 69 percent of all global water use, while industry and domestic uses consume 23 percent and 8 percent, respectively (UNEP 1996). These figures have to be seen in the light of the 30-year outlook from the UN predicting a 45 percent increase in population and a doubling of industrial water use.

The problem is twofold. More water is needed in cities because of expanding populations as well as industries. On the other hand, the agriculture sector is under pressure to accommodate the need for increased food production. Therefore, a better utilization of the limited water sources is the only solution for most developing countries. Diverting wastewater produced in cities and industries to the agricultural sector is an increasingly used option (Al-Nakshabandi et al. 1997; Asano and Levine 1986). Wastewater from urban areas contain high amounts of organic and inorganic matter, especially nitrogen, phosphate, and micronutrients that are of utmost importance to agricultural soil. Seen in this light, reusing wastewater not only helps to alleviate water scarcity in arid zones, but could also be a valuable source in recycling the nutrients once exported from the agricultural areas to the cities. The wastewater, however, contains other components, which are hazardous to human health, especially a high content of pathogens discharged with domestic sewage and toxic compounds, such as heavy metals associated with industrial wastewater (Blumenthal et al. 1991). The irrigation water available to the rural domestic user should therefore, in many cases, be regarded as diluted sewage.

Recognizing the reuse of urban wastewater mixed with other sources of irrigation water, calls for a precise knowledge of the health effects on humans. This knowledge is currently lacking (Ault 1981). Numerous studies have been carried out into different aspects of reusing wastewater for agricultural purposes (Biswas 1993). However, these studies and guidelines have focused on the occupational health hazards to farmworkers irrigating with wastewater and the effects of aerosol contamination on people living in or next to areas (mainly golf courses) where wastewater is applied by sprinkler irrigation (FAO 1992; Shuval et al. 1986; WHO 1993). None of the guidelines or investigations considers possible domestic uses of irrigation water in irrigation schemes in the developing countries. It is assumed that the water is used strictly for agricultural purposes and that alternative sources of water are available for other uses, including domestic use (WHO 1989; FAO 1992).

Water quality monitoring is well established in the developed world. However, a discussion regarding the suitability of different bacteria as indicators of fecal contamination has been going on for some years and problems arise especially when monitoring methods have to be designed made for the tropics. The tradition in temperate zones of the world has been to use a total coliform bacterial count as a fecal pollution indicator, and is proposed in the international guidelines (ibid.). But investigations have shown that they are less suitable in a tropical climate due to the possibilities of after-growth outside the host organism (Gleeson and Gray 1997). Therefore, researchers are turning towards the use of the fecal indicator bacteria *E. coli*, although there is evidence that a possible after-growth can take place in an aquatic environment under favorable conditions (high temperature and nutrients levels) (ibid). But *E. coli* is widely recognized as the best fecal indicator for field-testing, due to the simple, fast, and relatively cheap analyzing technique. However, it has to be borne in mind that lack of *E. coli* in a water sample does not directly indicate that the water is free of contaminants; many helminths and viruses are able to survive for long periods of time after bacteria like *E. coli* have perished (ibid.). There is however still a lack of knowledge on how *E. coli* behaves under tropical aquatic conditions, and on how to identify the association between the known parameters that could influence the survival/die-off of the bacteria.

The literature shows there are certain parameters that can influence the survival rate of *E. coli*. The most important are pH, dissolved oxygen (DO), temperature, turbidity, salinity, nitrate, nitrite, ammonium, phosphorus, and Biological Oxygen Demand (BOD) (Gleeson and Gray 1997; Davies and Evison 1991; Joyce et al. 1996; Barcina et al. 1989; Reed 1997). Most of these parameters have been identified under controlled laboratory experiments, and the relative importance of the different parameters among themselves in a tropical climate has not been looked at. The task of doing so is very difficult, but may only be done via a computer model that is capable of calculating the interaction of chemical and physical parameters over a period of time in a system. Calibrating such a model with actual measurements from an irrigation system will therefore give a more in-depth understanding of which parameters have a direct influence on the pathogenic survival in a tropical irrigation canal. This will not only allow prediction of the impact of an additional wastewater introduction to an area but will also make it possible to assess the impact the different irrigation management practices like wet/dry irrigation, demand-based irrigation, etc. (water availability and retention time in the system) could have on the water quality, and to evaluate different drinking water treatment scenarios (use of stabilization ponds, sand filters, etc.).

The preliminary results show that there are clear differences in the contamination levels at different sources in the villages. Where the seepage water is nearly free of *E. coli* (1-10 CFU/100ml.) the tank and canal water show high numbers of *E. coli* 10^2- 10^5 CFU /100 ml. Regarding the in-house testing of drinking water containers, a heavy contamination of the drinking water (10^1-10^5 CFU/100 ml.) is found to be taking place within the household itself. Comparisons of results with the epidemiological study have not yet been made due to the limited monitoring period.

OBJECTIVES

Development Objective

To reduce the incidents of water-related diseases in areas where people use irrigation water for domestic purposes.

Immediate Objectives

i. To assess the microbiological water quality in an irrigation scheme in relation to drinking water sources, human behavior, and water storage procedures.

ii. To investigate and predict the changes in the microbiological water quality within an irrigation system, by use of a one-dimensional computer model.

iii. To determine the association between human health and the microbiological water quality of the irrigation water used for drinking purposes.

METHODS

Study Area

The Hakra 6R Distributary is the sixth largest distributary in Pakistan located in southern Punjab (close to the Indian border) on the edge of the Thar desert. Due to its location, the area has very limited natural water resources and an extreme climate. The temperature ranges from 0 °C in January to 46 °C in July and the average annual precipitation is 196 mm. The groundwater in Hakra 6R area is brackish and not suitable for drinking or irrigation and the inhabitants are totally dependent on irrigation canal water for *all* water uses (uz Zaman and Bandraragoda 1996).

Hakra 6R has 78 villages with a population of approximately 136,000. Hakra 6R is a very poor area with the population dependent only on cultivating low-value crops like sugarcane, cotton, vegetables, and wheat. The head end of the distributary is seriously waterlogged and partly unsuitable for agriculture (ibid.).

The total length of the system is 135 km (ibid.). The distributary receives its water from Sulemanki headwork from where irrigation water is distributed to the different systems in South Eastern Punjab. The inflow to the headwork comes partially from Sutlei river that originates in India and partially from a big canal connected with Ravi river. The Ravi river is receiving all wastewater from the city of Lahore, situated about 250 km upstream (see map 1).

Two hundred households in 10 of the 78 villages were randomly selected (see map 1) and 5 households with different drinking water sources in each village were selected for sampling drinking water from the container inside the household.

Table 1. Sources for drinking water.

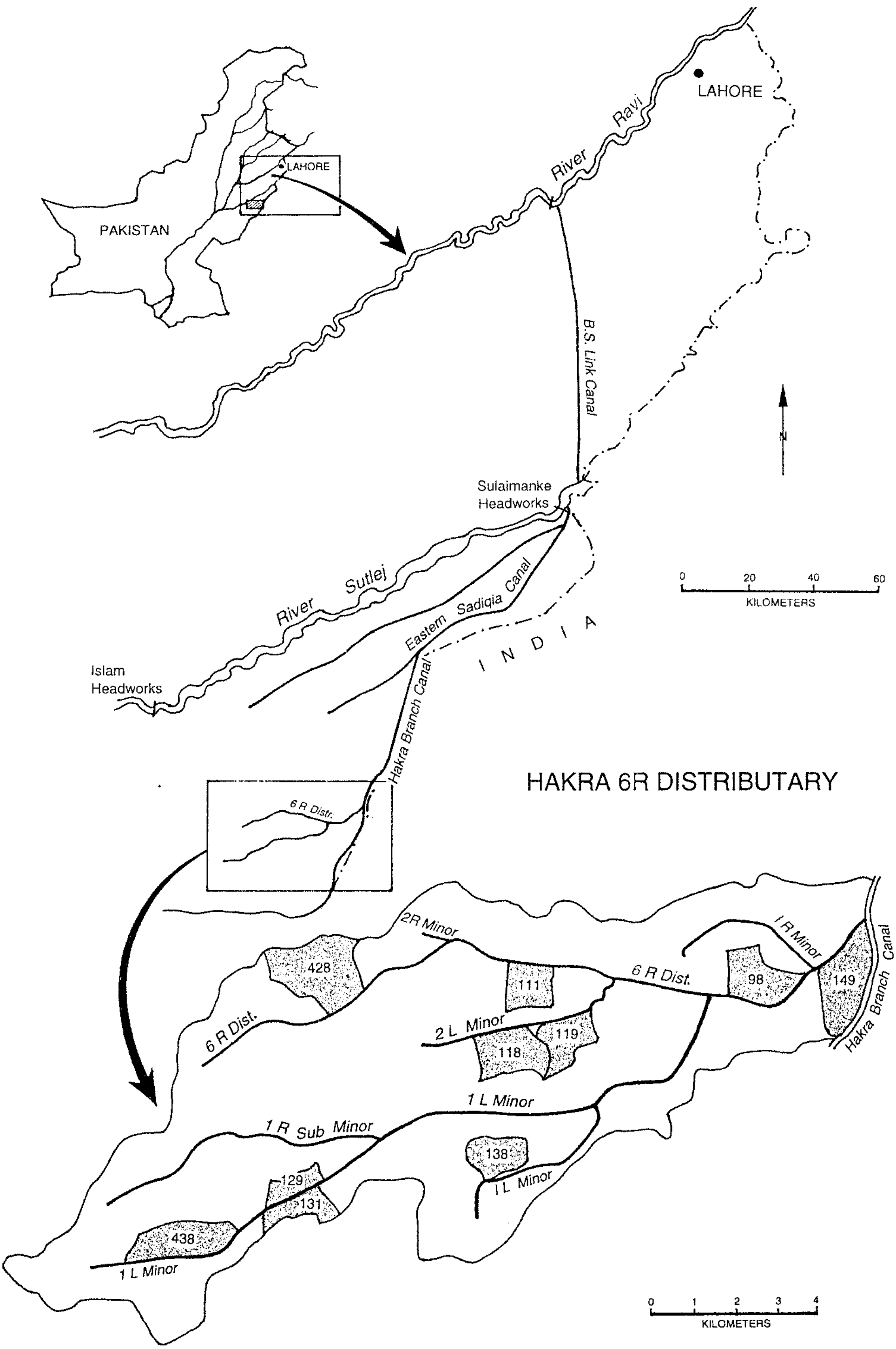
Village no.	149	98	119	138	118	111	438	129	131	428
Location (head, middle, tail)	H	H	M	M	M	M	T	T	T	T
No. of households in sample	11	29	22	15	16	29	9	27	9	33
No. of persons	86	222	150	116	115	260	70	222	63	231
Use of drinking water sources (% of households in each village)										
Water tank	0	0	0	7	0	17	44	26	0	3
Seepage from tank/canal/fields	100	100	55	93	66	73	66	59	78	97
Water course (direct)	0	0	0	0	0	10	0	0	0	0
Water supply scheme	0	0	45	0	44	0	0	0	0	0
Open well	0	0	0	0	0	0	0	15	22	0

All villages in the area have the same layout (see map 2). The center of the village is a big square where the open village tank is located. The village tank is filled weekly from the watercourse, which runs parallel to the village boundary. Many households are connected via small PVC pipes inserted directly into the tanks. In the vicinity of most tanks there is a well, which is directly connected to the tank by an underground drain, and from which water is drawn manually. Shallow groundwater/seepage is drawn from beneath the water tank at the village boundary adjacent to the agricultural field, or next to the canals. Seepage water is taken from a depth of 1-4 m from the ground surface. It is drawn either by hand pumps on-site or via pipes connected to individual households. The open wells also utilize the seepage water at various places.

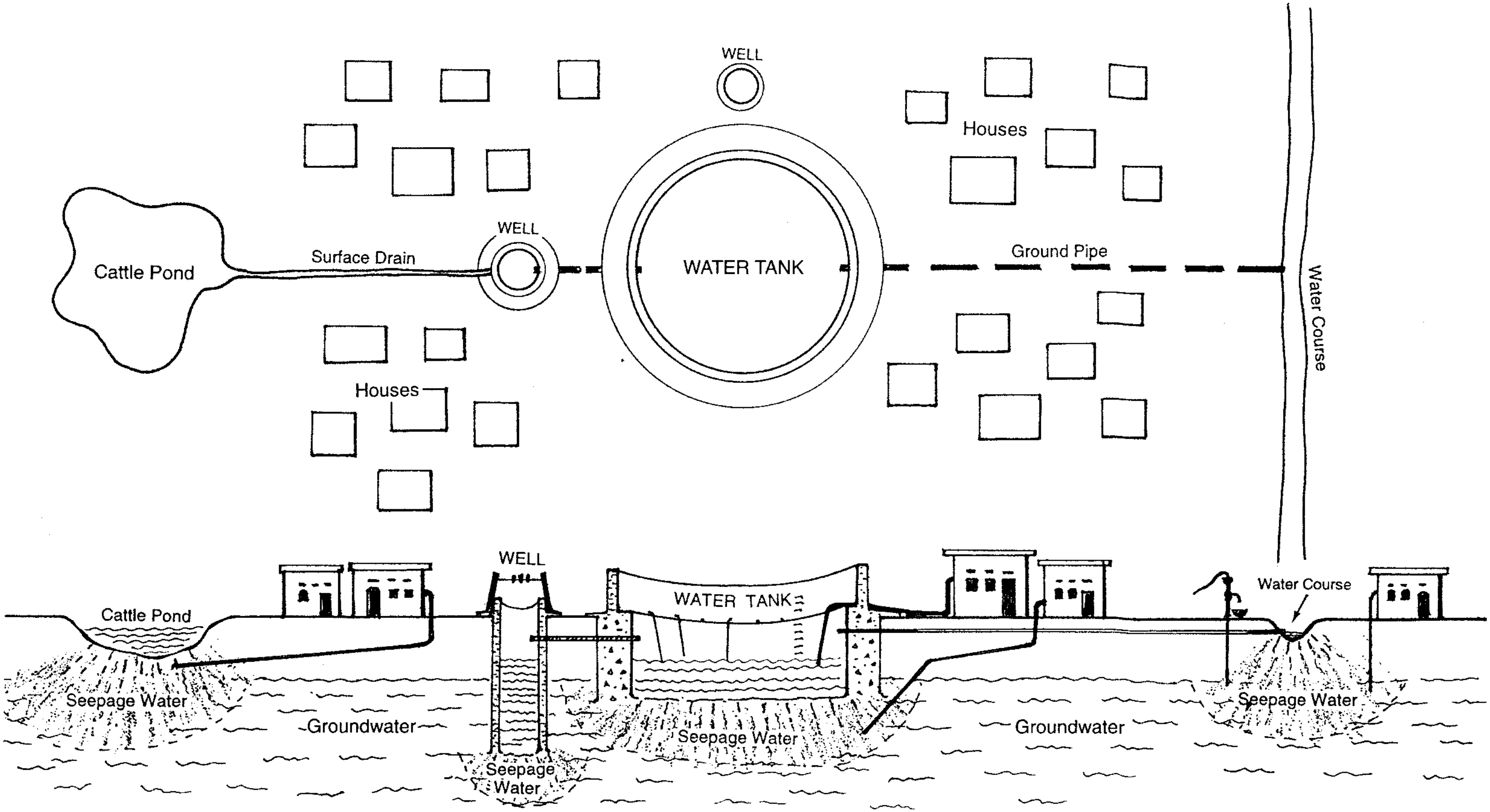
Two villages receive water from public water supply schemes. One village has facilities of slow sand filtration and chlorinating (118/6R). The other has a partially filled slow sand filter, which is basically a pond with very small retention time (119/6R).

All the drinking water sources originate from the irrigation water in Hakra 6R Distributary, either directly or indirectly, by exploiting seepage water. Thus, the initial water quality in the distributary will affect all the domestic water sources mentioned above.

Map 1. Layout of Hakra 6R.



Map 2. Layout of the village.



Assessing the Water Quality

Microbiological tests will be carried out at all the identified drinking water sources in the villages and the 50 identified household containers. This will make it possible to evaluate whether the contamination found in the storage containers originates from within or outside the household. It will also establish whether different storage practices have an influence on the contamination level, storage in special/traditional containers, etc. The types of *E. coli* present in the samples will also indicate if *E. coli* is capable of causing a health risk, i.e., some strains of *E. coli* like *E. coli* O157 have proven to cause diarrhea (Greenwood 1992). The testing for virulence genes cannot be carried out in the field; therefore, isolated *E. coli* will be brought to KVL for analysis.

Since no continuous water supply is normally present in irrigation areas, the study will investigate what effects the storage of drinking water in village tanks has on the microbiological water quality. Does it have a positive effect (bacteria die-off due to retention time/temperature and sunlight exposure)? Or does it have a negative effect due to external contamination from air deposits, inflow of wastewater to the tanks, regrowth, etc.? Evaluation will also be carried out of different drinking water treatment/storage scenarios at village level (slow sand-filtration, chlorination, or controlled seepage).

Modeling

This part will monitor/model the changes in the water quality down through the canal system and investigate possible associations between the inflow water at the head of the system and the actual contamination levels found in the households. This will not only allow prediction of the impact of an additional wastewater introduction to the area but will also give a more in-depth understanding of the parameters that have a direct influence on the survival and removal of fecal bacteria in tropical aquatic systems.

The model will use the intensive campaign measurements for calibration purposes and the less complex daily measurements for extrapolations between the campaigns, enabling simulations of the water quality in the entire study period. Modeling based on calibration from actual measurements will make it possible to assess impact of the different irrigation management practices such as wet/dry irrigation and demand-based irrigation. All these practices will affect the water availability in the system and thus the irrigation water retention times and flow rates.

Association between Water Quality and Human Health

The association between irrigation water quality and human health among the nonagricultural water users in Hakra 6R will be established with statistical tools. This part of the study will be done in close collaboration with the simultaneously ongoing epidemiological study carried out by IWMI. The epidemiological study will monitor the 200 selected households for a 1-year period to document the occurrence of waterborne diseases. The relation between the presence of bacterial indicators in drinking water sources/containers and the occurrence of waterborne diseases, especially diarrhea, within the different households will be studied. Quantities of water available, sanitation practices, and hygienic behavior will be included as the main potential confounding variables. Further, a comparison between the two villages with a piped drinking water system (especially no. 118 with a chlorinated drinking water system), and the rest of the study area will be made. The purpose of this is to see if the direct use of irrigation water for drinking purposes has a significant impact on the health status of the households.

PROJECT PLAN

Set out below is the methodology and predicted outcome of the study for each of the objectives described.

Studies Included under Objective I

1. Assessment of the presence of *E. coli* in all drinking water sources and in household containers in the selected villages.
2. Assessment of the water quality changes in the village tanks between fillings.

Method Used

Ia) Every week, water samples will be taken from all the identified drinking water sources in the villages plus the fifty selected household storage tanks/containers. The storage procedure and type of storage container within the individual household will be identified and registered at the time of sampling. The samples will be analyzed for enumeration of *E. coli*. Samples will be taken in 150 ml. sterile sampling bags. If chlorine is present in the water a dechlorinating agent will be added. The transport time from the first sample until filtration in the laboratory will not exceed 4 hours (Bartram and Balance 1996). The sample will be analyzed via filtration technique on a Milipoore 0,45 mm membrane filter. The filter is then placed on a m-Coliblue 24^{0} agar, a *E. coli* specific selective agar, and incubated for 24 hours at 35 °C, for enumeration of *E. coli* (HACH 1997). Isolates of *E. coli* will be tested in Denmark for violence genes by colony hybridization method or PCR techniques.

The results found will be statistically investigated to see if there are any significant differences in the *E. coli* level, between villages and households with different water treatment/storage practices.

Ib) Five randomly selected tanks will be monitored daily in the 7-day period between fillings, or until the tank is refilled. This will be done once per selected tank during the wet and dry seasons. The time of each filling and water levels before and after filling will be noted and measured. For estimation of seepage losses and concentration changes the precipitation and evaporation (multiplied by a coefficient to correct for tank structure) will be measured by pan. This will be done at a central place in Hakra 6R. Samples will be analyzed for *E. coli*, electrical conductivity (EC), pH, DO, temperature, turbidity, fluoride, sodium, total-hardness, iron, salinity, nitrate, nitrite, ammonium, phosphorus, BOD, and COD.

One sample of the inflow water at filling and a daily sample from the tank itself will be taken. At each sampling site 1.7 liters of water will be collected in prewashed plastic bottles (deionized water). After filling the bottles will be immediately put into cool boxes containing prefrozen elements and transported to the laboratory. If the inorganic testing cannot take place within 4–6 hours after sampling, they will be preserved with acid. For bacteriological sampling and analysis see Ia. Parameters such as pH, EC, sodium, and DO will be measured on-site using electrodes. The remaining parameters will be measured in the field-station laboratory, using a HACH spectrophotometer DR/2010 or titration according to the standardized method (HACH 1997).

Predicted Outcome of Study

Ia) The results will indicate the water quality of the different sources in the villages, allowing a possible assessment of the contamination level the selected households are exposed to via their drinking water source, and if the *E. coli* in itself poses a health risk. Further, it will be possible to estimate the in-house contamination and to see the difference in storage practices and storage containers (clay/brass). An assessment of different drinking water treatment scenarios in an irrigation scheme will be done to investigate if it is desirable to use high-tech solutions, such as chlorination, or traditional solutions like utilization of seepage water.

Ib) The monitoring will show the variation of water quality in the village tank between the fillings. This would make it possible to assess if different factors like sunlight and temperature have an effect on the die-off or possible multiplication of the bacteria, thus indicating the die-off rate in the system.

Studies Included under Objective II

1. Monitoring the water quality changes in the canals.
2. Modeling the microbiological changes in the system.

Method Used

IIa) This study consists of daily monitoring and four measuring campaigns. The campaigns have to be carried out every 3 months to cover different climatic and agricultural seasons. Each monitoring campaign will last 24 hours. Measuring stations will be set up at seven structures (canal intersections) in the system where a half-hourly recording of water level will take place. At each station the water quality will be measured four times during the campaign (parameters as Ib). The structures from where the measurements are taken will be calibrated to establish the H/Q (water level/flow) relationship for each structure.

Pretesting will make it possible to construct a sampling technique whereby one sample will represent the concentration in the cross section of the water body (Bartram and Balance 1996). The monitoring of DO, pH, and turbidity will take place both upstream and downstream from the structure, due to the total mixing at downstream. For sample size, handling, and analyzing technique see Ib.

A daily sample will be taken from Hakra 6R at one of the measuring stations. This will include: *E. coli*, pH, DO, temperature, and turbidity. At two places in the system the water level will be recorded daily together with rainfall, evaporation, temperature, and solar influx data from a meteorological station to be set up in the middle of Hakra 6R.

IIb) The model to be used is the Mike 11 surface water quality model from Danish Hydraulic Institute. The input to the model will be the data collected in IIa. Blue prints of the Hakra 6R Distributary will be obtained from the Irrigation Department in Bahawalnagar, to give the dimensions for cross sections and distances within the system. The two practices, wet/dry irrigation and demand-based irrigation will be tested by creating scenarios where the specific type of irrigation is carried out in the area using the background data from the calibrated model.

Predicted Outcome of Study

IIa) From the four campaigns it would be possible to have a 4x24 hour in-depth knowledge of how the canal system affects the different parameters in question, and to determine the difference in the water quality at different water flows, temperature, sun light exposure, etc.

IIb) The model will not only allow prediction of the impact of an additional wastewater introduction to the area but will also give a more in-depth understanding of which parameters have a direct influence on the pathogenic survival in a tropical irrigation canal. An evaluation will be made of the different irrigation management procedures in respect to their treatment effect on polluted irrigation water.

Study Included under Objective III

IIIa) Determine the association between human health and the microbiological water quality of the irrigation water used for drinking purposes.

Method Used

IIIa) Statistical analysis using SPSS[a] 6.0 (Nurusis 1993). Statistical software for epidemiological analyses, will correlate the *E. coli* levels found in the drinking water sources to the diarrhea cases in the households, obtained in the epidemiological study. The epidemiological data have been obtained via weekly visits to the households and with a week recall period to quantify the daily occurrence of diarrhea cases for the different family members.

Predicted Outcome of Study

IIIa) Via the statistical results, it will be possible to determine if there is a connection between the irrigation water quality/drinking water source and the diarrhea cases in the households. It will also be possible to detect if there is a difference in the disease pattern among the villages for those with water supply schemes and those without. Further, it will be possible to determine if the key contamination source is at the source or in the household itself.

OUTPUTS AND PROJECT BENEFICIARIES

The overall beneficiaries of the project will be the poor farming communities living in the irrigation areas in the developing countries, whose drinking water resources are under threat by factors beyond their influential sphere. The project target group will therefore be water supply and irrigation system planners in the tropics, at both national and international levels, and researchers who are investigating public health and pathogens' survival in tropical aquatic systems, and who have a direct influence on the overall water resources management. On the basis of the identification of the important parameters, and on the recommendations given regarding health impact minimization weighed against the feasible low-cost technologies for treatment and irrigation management, these people will be able to incorporate the needs of the domestic users in their future planning/research.

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