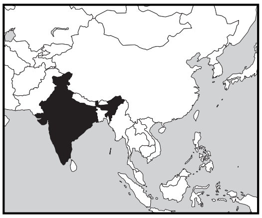

Wastewater irrigation in Hubli–Dharwad, India: implications for health and livelihoods

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SUMMARY: *The availability of permanent streams of sewage-contaminated wastewater emanating from the twin city of Hubli–Dharwad in India has enabled small-scale farmers to diversify their cropping practices. Close to the cities, farmers have adopted a year-round, intensive vegetable horticultural system. Not only do the nutrients in the wastewater increase crop yields, but this practice is particularly lucrative during the dry season when wholesale market prices rise between two- and six-fold. Further away from the cities, less intensive farming systems are used, but the wastewater still confers advantages in terms of early-season irrigation and increasing production from fruit trees in agroforestry systems. However, there are adverse health implications, including bacterial contamination of vegetables and intensive application of pesticides to combat the insect pests that infest these crops. Ways of managing these adverse effects are discussed.*

I. INTRODUCTION

IRRIGATION WITH WASTEWATER is a fact of life in and around urban areas in many low-income countries. This paper considers the effects of the availability of such a perennial water resource in a semi-arid, peri-urban environment, and its effects upon livelihood practices of farmers and the implications for health.

The studies were conducted in and around Hubli–Dharwad, the second largest urban agglomeration in Karnataka, after Bangalore, the state capital. The twin city was formed in 1962, when Hubli and Dharwad were brought together under the Hubli–Dharwad Municipal Corporation and, today, is a transport hub and home to 736,000 people. Hubli, the larger of the two cities, is a regional centre for commerce, trade and industry, while Dharwad, located 22 kilometres to the northwest, is host to several higher education institutions. The city has a rapidly expanding information technology sector alongside well-established commerce and service sectors but, despite this, the traditional practice of agriculture in and around the city remains strong and continues to play an important social and economic role.

The climate of Hubli–Dharwad is semi-arid and the rainfall across the peri-urban area varies, exceeding 1,000 millimetres to the west of Dharwad and being less than 700 millimetres to the east. The mean annual rainfall is 810 millimetres (Figure 1), distributed in a weakly bi-modal pattern, the bulk of the rain falling during the southwest monsoon (June to September),

Figure 1: Mean annual rainfall (1952–1998) recorded at University of Agricultural Sciences, Dharwad

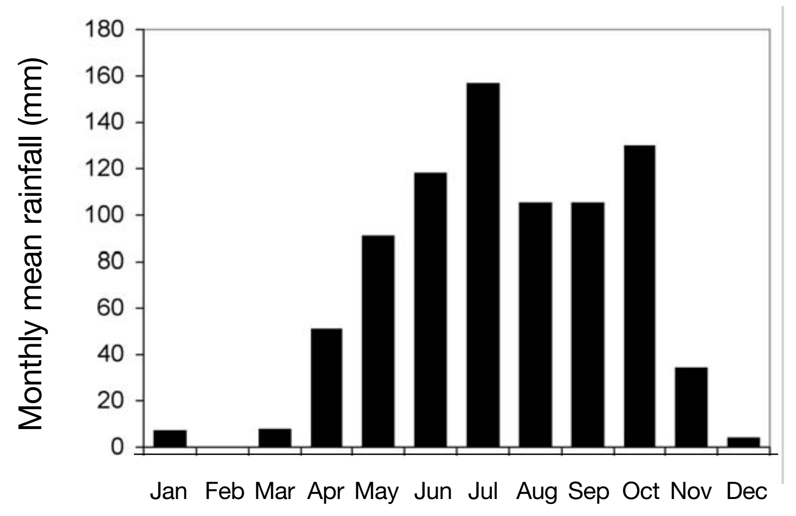
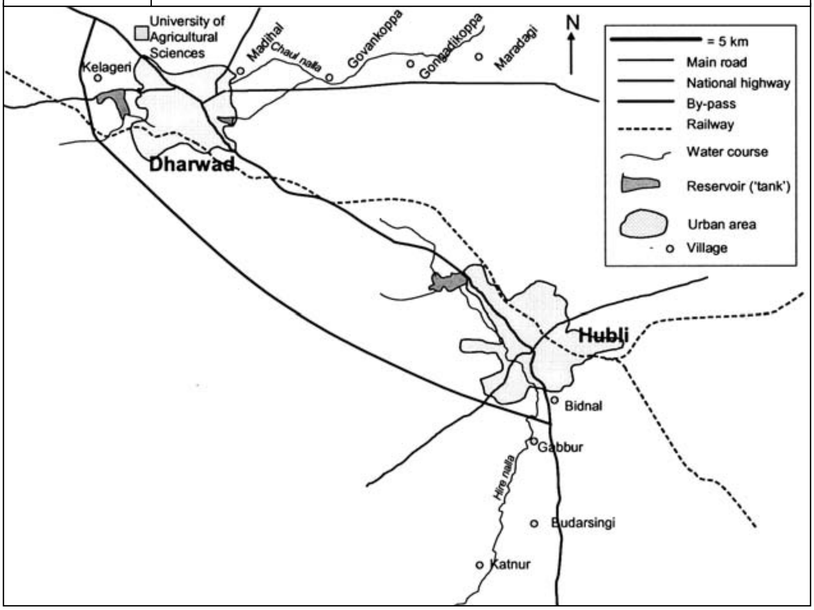


Figure 2: Map of Hubli–Dharwad, showing location of study villages, main watercourses (*nallas*) and lines of communication



otherwise known as the *kharif* season. Within the twin city, an estimated 60 million litres of wastewater is generated per day. This flows, untreated, via sewers and wastewater *nallas* (open drains) into natural watercourses that flow into the hinterlands (Figure 2). As water supply to the city improves, the amount of wastewater is likely to increase significantly.(1) In Dharwad, the main easterly sewer emerges at Madihal, once an outlying village but now incorporated as a suburb due to the expansion of the city. From

(DFID) for the benefit of low- and middle-income countries. The views expressed are not necessarily those of DFID. In particular, the authors wish to thank the DFID Natural Resources Systems Programme for financial support for some of this research, and S R Salakinkop and G Praveen for their valuable contributions.

1. See Hollingham, M (2003), "Artificial groundwater recharge and water quality around Hubli–Dharwad" (mimeo).

Madihal, the Chaul *nalla* flows east, past the villages of Govankoppa, Gongadikoppa and Maradagi. In Hubli, the main wastewater *nalla* (Hire *nalla*) flows to Bidnal, which is now also incorporated as a suburb of the city. From Bidnal, the *nalla* flows south to southwest, passing the peripheries of the villages of Gabbur, Budarsingi and Katnur. In both Dharwad and Hubli, the main areas of wastewater-irrigated agriculture are found along these two main *nallas*, although smaller pockets of wastewater irrigation can be observed in other areas of the city. Both *nallas* flow through deep to very deep, moderately well-drained, cracking montmorillonitic clay soils, mostly classified as typical chromusterts[2] and known locally as black cotton soils or vertisols. They are characterized by a high water-holding capacity and moderately high fertility, but are difficult to cultivate due to their swelling and cracking nature.

2. Soil Survey Staff (1999), *Soil Taxonomy* (2nd edition), United States Department of Agriculture, Agriculture Handbook No 436, US Government Printing Office, Washington DC, 870 pages.

II. METHODOLOGY

SURVEYS WERE CONDUCTED at intervals between 1997 and 2001, as components of a number of projects funded by the UK government's Department for International Development (DFID). Most information was obtained by discussing farming systems with farmers in their fields. During 1997 and 1998, a survey of wholesale vegetable prices in Dharwad market was undertaken to determine seasonal fluctuations; and between November 1998 and October 1999, a study of the quality of sewage water was conducted by Renukaprasanna.[3] Monthly samples were collected at 1 kilometre intervals to a distance of 10 kilometres, starting from the outskirts of Hubli and Dharwad.

3. Renukaprasanna, M (1999), "Characterization of Hubli–Dharwad urban sewage and its impact on soil properties", MSc thesis, University of Agricultural Sciences, Dharwad, India.

Until 2001, most fieldwork was confined to Madihal but, in 2001, this was expanded to a transect-based study. The first phase consisted of an orientation and familiarization survey of the farming systems located along the main Dharwad and Hubli wastewater *nallas*. The results of the preliminary survey were used to select the peri-urban villages that would be targeted during a second survey, and consideration was given to ensuring that a wide geographical area was covered in an attempt to identify spatial patterns and trends. The second phase consisted of the main survey, and incorporated semi-structured interviews, cropping calendars and farm transect walks. For the main survey, interviews were held with 25 farmers, primarily smallholders with plots of less than one hectare. In the Indian context, these are generally considered to be "small" farmers, which is often equated with being poor. Samples of vegetables were also taken for bacteriological analysis.

III. WASTEWATER-IRRIGATED AGRICULTURE

a. Main cropping patterns

ALONG THE MAIN Dharwad and Hubli wastewater *nallas*, three distinct cropping systems are evident: vegetable production, field crops with vegetables, and agroforestry. The spatial distribution of the cropping systems results from a combination of factors that include labour availability, farm size, market access, tradition within each village, and soil types, with the overriding aspect being the availability of wastewater itself. In the city and its suburbs, where wastewater supply is guaranteed, intensive

Table 1:	Spatial variation of wastewater-irrigated cropping systems		
Main *nalla*	Village	Distance from Dharwad or Hubli centre (km)*	Dominant sewage-irrigated cropping system
Dharwad (Chaul *nalla*)	Madihal	2.0	Vegetable production
	Govankoppa	5.4	Field crops & vegetables
	Gongadikoppa	9.2	Field crops & vegetables
	Maradagi	11.85	Field crops & vegetables
Hubli (Hire *nalla*)	Bidnal	2.5	Vegetable production
	Gabbur	8.9	Field crops & vegetables
	Budarsingi	10.7	Agroforestry
	Katnur	13.5	Agroforestry

*Distance = length of the wastewater *nalla* from city source to village including any meander.

vegetable production takes place. In locations where the supply is less reliable, field crops and agroforestry predominate (Table 1).

b. Irrigation methods

Photo 1: Wastewater being discharged at the head of the field to flow through furrows to the crops

Regardless of the cropping system used, the wastewater irrigation method along the Dharwad and Hubli wastewater *nallas* remains the same. It consists of an overland flow and furrow irrigation system using a centrifugal pump powered by either a diesel motor or grid electricity (Photo 1). The irrigation pump and diesel motor together constitute the highest investment cost, and therefore they are often housed in small brick buildings adjacent to the wastewater *nallas* for security and protection against the elements. Wastewater is lifted from the *nallas* by means of the pump and delivered under pressure to the highest field elevation. The distance from the wastewater off-take to the actual outlet may be up to 500 metres. From the outlet point, the wastewater flows under gravity along the furrows, irrigating the crops. The opening and closing of the furrows is a precisely timed operation, to ensure that soils are not left waterlogged and ridges are not inundated.

Most farmers have adopted some method of filtering the wastewater as it is pumped from the *nalla*. The filtration serves two purposes: it stops

Table 2: Chemical parameters of sewage in Hubli and Dharwad 1998 and 1999

	Distance along water-course (km)	pH	EC (dS/m)	SAR	RSC (me/l)		Total susp-ended solids (TSS) (mg/l)
					Feb–May (Summer)	Oct–Jan and June–Sept	
Hubli	1	6.78	1.69	3.32	5.57	1.92	228
	2	6.82	1.68	3.32	5.62	1.98	205
	3	6.84	1.67	3.33	5.63	1.86	192
	4	6.90	1.63	3.30	5.59	1.69	181
	5	6.94	1.61	3.34	5.31	1.91	167
	6	6.97	1.60	3.33	5.29	1.61	150
	7	7.03	1.60	3.34	5.01	1.69	131
	8	7.07	1.58	3.38	5.13	1.65	117
	9	7.12	1.57	3.37	4.76	1.50	100
	10	7.16	1.56	3.35	4.60	1.46	94
Dharwad	1	6.82	1.44	3.04	7.05	3.12	189
	2	6.91	1.42	3.03	7.10	3.05	174
	3	6.94	1.40	3.01	6.86	3.01	157
	4	7.25	1.20	2.54	6.85	3.72	102
	5	7.10	1.33	3.00	6.93	2.95	122
	6	7.17	1.33	2.97	6.90	2.84	105
	7	7.21	1.32	2.96	6.90	2.74	88
	8	7.29	1.31	2.95	6.77	2.56	77
	9	7.37	1.30	2.94	6.48	2.43	70
	10	7.42	1.30	2.96	6.40	2.53	53

EC = electrical conductivity
RSC = residual sodium carbonate
SAR = sodium adsorption ratio
TSS = total suspended solids
Safe limits of irrigation water: pH = 6.5–8.5; EC = 3dS/m; SAR = 10; RSC = 2.5 me/l; TSS = 100 (Kale, C K, R D Reddy, M Radhakrishna Murthy, V P Deshpande, L Shanikumar, Venkat Rao and V Subbiah (1992), "Irrigation quality characteristics of the wastewater streams of Hyderabad", *Indian Journal of Environmental Health* Vol 34, pages 226–235).

debris from entering the pump, thereby reducing wear and tear, and it prevents the fouling of soils with any debris and solid wastes present in the wastewater. The various forms of filtration include improvised gauze filters around the inlet pipe, positioning the inlet pipe inside pierced plastic barrels, which act as large sieves, and using sieve baskets woven from natural fibres.

c. Wastewater properties

Sewage-contaminated wastewater is often assumed to have a high nutrient load. However, research analyzing sewage-contaminated wastewater has shown that for many plant nutrient ions, concentrations in wastewater are in fact similar to those from borehole water.(4) The main differences between sewage water and water from boreholes recorded at various sites around India(5) have been for total suspended solids (TSS) and its associated bio-

4. Yadav, R K, B Goyal, R K Sharma, S K Dubey and P S Minhas (2002), "Post-irrigation impact of sewage effluent on composition of soils, crops and groundwater – a case study", *Environment International* Vol 28, pages 481–486.

5. Gupta, A P, R P Narwal and R P Antil (1998), "Sewer water composition and its effect on soil properties", *Bioresource Technology* Vol 65, pages 171–173; also Das, D C and R N Kaul (1992), *Greening Wastelands through Wastewater*, National Wastelands Development Board, Ministry of Environment and Forests, New Delhi, India, 64 pages.

logical oxygen demand (BOD), and sometimes for dissolved nitrate ions, although the latter varies from site to site. In this study, the only value recorded for dissolved total nitrogen in wastewater was modest (12 mg/l).[6] In another study of the chemical content of water from boreholes in several villages around Hubli–Dharwad,[7] nitrate levels were found to vary between zero near the urban areas to 20 mg/l in villages 10 to 15 kilometres from the city centres. In the more detailed study undertaken by Renukaprasanna,[8] it was found that values for the various parameters were generally higher during the dry season (February–May) and lowest during the rainy season (June–October) (Table 2). All the parameters, except residual sodium carbonate (RSC) and TSS, were found to be below critical limits for irrigation. The RSC values during the dry season were higher than critical limits, more so in Dharwad. Thus, the water is not fit for irrigation in the dry season, as it may cause sodicity (the accumulation of sodium) and/or salinity (the accumulation of soluble salts) in soils, decreasing soil productivity and adversely affecting soil structure, a fact often reported by farmers. High values for TSS would raise BOD, killing vertebrate life in the watercourses by depriving them of oxygen. However, these solids also contain nutrients (not determined), thus raising the fertility levels of soils where wastewater is used for irrigation. In this study, soil fertility was not determined, but other studies have found that irrigation with wastewater has led to increased soil organic matter content and available nutrients (N, P and K).[9] As there are no heavy industries in Hubli–Dharwad, the presence of heavy metals was below the permissible limits in both the sewage streams.

6. In a sample taken at Madihal in 1997: pH = 7.6; EC (dS/m) = 0.42; TSS = 110; RSC and SAR were not measured; total N in solution (Kjeldahl) = 12.1 mg/l. See Table 2 for explanations.

7. Cratchley, R, M Hollingham and S G Joshi (2001), "Annex E: water resources around Hubli and Dharwad", in Brook, R M (editor) (2002), *Filling Gaps in Knowledge about the Peri-urban Interface around Hubli–Dharwad*, DFID Project R7867 Final Technical Report, University of Wales, Bangor, UK.

8. See reference 3.

9. See reference 5.

d. Vegetable production

This very intensive production system is found predominantly in Madihal, near Dharwad, and in Bidnal, on the outskirts of Hubli. A distinct feature of this system is the year-round production of vegetables for sale and the absence of a fallow period (Table 3). Proximity to the urban areas – i.e. the source of wastewater – ensures a reliable irrigation supply during the dry season. Ease of access to local urban markets and high urban demand ensure a secure market for vegetable produce, particularly during the dry season when vegetable wholesale market prices increase between two-fold (amaranthus, cauliflower) and six-fold (tomato) (Figure 3). The intensive vegetable production system requires considerably higher labour inputs than field-crop and agroforestry-based systems. Household members normally provide these labour inputs, but during peak periods additional farm labourers may be hired.

A major reason why labour inputs are high is that irrigation with wastewater leads to a problematic increase in the incidence of weeds and pests, which have to be controlled if total loss of crop is to be averted. This increased incidence is the result of a combination of factors. Pests are habitually controlled by blanket-spraying with insecticides (organophosphates, organochlorines and synthetic pyrethroids are all used); however, the hot climate provides opportunistic breeding conditions by quickening insect reproductive cycles, which then enables pests to build up pesticide resistance faster. Farmers report multiple pesticide resistance in the main pest species. The planting of vegetable crops in monoculture plots also facilitates pest proliferation, while the continuous cycle of crop production during the dry season, when land is normally barren, ensures that insect populations can thrive when they would typically encounter a seasonal decline.

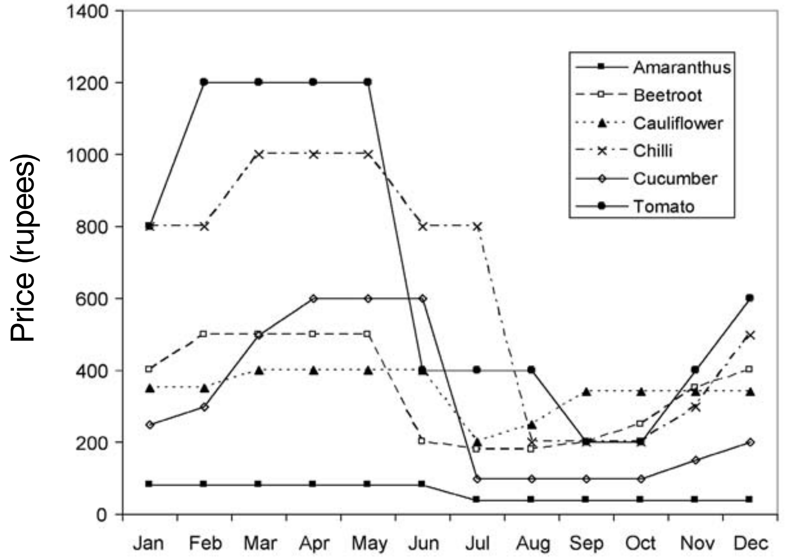
Table 3: Madihal: four examples of vegetable cropping patterns, 1997/1998	
Farm 1 Knol khol (June–August) Spinach beet (September–December) (four harvests from same crop)	**Farm 2** Cauliflower (June–August) Red amaranthus (September) Fenugreek (October) Spinach beet (November–January) (three harvests)
Farm 3 Red amaranthus (June–July) Red amaranthus (August–September) Red amaranthus (November–December) Red amaranthus (January–March) Red amaranthus (April–May) (each crop was harvested twice before replanting)	**Farm 4** Cauliflower and beetroot (July–September) Spinach beet (September–November) (three harvests) Red amaranthus (December–January) (two harvests) Coriander (February)

SOURCE: Hunshal, C S, S R Salakinkop and R M Brook (1997), "Sewage-irrigated vegetable production systems around Hubli–Dharwad, Karnataka, India", *Kasetsart Journal (Natural Sciences)* Vol 32, No 5, pages 1–8.

10. Scientific binomials and Indian vernacular names for vegetables and crops are listed in Table 5.

Due to the lack of effective control, the prolific multiplication of pests such as the diamond-back moth *(Plutella xylostella)* and the cotton bollworm *(Helicoverpa armigera)* has resulted in complete crop failures and high economic losses; consequently, farmers in some areas have stopped growing what were once highly profitable crops, such as cabbage.(10) *Plutella xylostella* affects aubergine and most brassica species, while *Helicoverpa armigera* affects most vegetable crops. During interviews, farmers on both wastewater nallas identified *Helicoverpa armigera* as a major pest currently affecting aubergine, chilli, okra, onion and tomato crops. However, despite the failure of pesticides to provide effective crop protection, many farmers respond by increasing the frequency of pesticide application – with some farmers spraying twice weekly as they feel they have no other option – and

Figure 3: Monthly wholesale prices of vegetables in Dharwad market, 1997 and 1998



Note: Quantities vary depending on vegetable type; prices given are to indicate seasonal trends (£ 1 = Rs 70).

Table 4: Dharwad transect: typical examples of field and vegetable cropping calendars, 2000/01			
Village	June July Aug Sept	Oct Nov Dec Jan	Feb March April May
	Kharif (monsoon rains)*	*Rabi* (light rains)*	Dry season (summer)*
Govankoppa	Aubergine, chilli, ridge gourd, cucumber	Wheat	Aubergine, chilli, ridge gourd, cucumber
Gongadikoppa	Onion, okra, green gram, groundnut, cotton, banana	Chickpea, wheat, sorghum, banana	Fallow, cucumber, okra, ridge gourd, chilli, banana, tomato
Maradagi	Cotton, green gram, groundnut, onion, maize, ridge gourd, chilli	Chickpea, safflower, wheat	Fallow, cotton, chilli, tomato, onion

* Duration and timing of the seasons varies annually; for instance, the 2001 monsoon forecast for 7 June did not break until seven weeks later.

many also mix pesticides, creating potentially hazardous combinations. These practices are advocated by pesticide dealers, who remain the chief source of agricultural advice for farmers.

Due to the high nutrient load in the solid fraction of the wastewater, weed growth is prolific. Farmers reported that the most problematic were *Portulaca oleracea* and *Cyperus rotundus*, which were controlled by hand-pulling and hoeing as often as every two weeks during the maximum irrigation period, and which could be composted or fed to livestock. Another pernicious weed, *Parthenium hyterophorus*, is reputed to be spread by seeds in wastewater. It is toxic to livestock and cannot be composted, as the seeds survive the process, so the only feasible method of control is hand-pulling and burning. One farmer had been given *Zygogramma* beetles by the University of Agricultural Sciences, which act as a bio-control agent for this weed, but control is only partial. There was no reported use of any herbicides.

e. Field crops with vegetables

It is noteworthy that the belt of intensive, wastewater-irrigated vegetable production is very confined, occurring only in the immediate surrounds of Madihal and Bidnal. Once beyond Madihal, on the Dharwad *nalla*, the predominant cropping system is cash arable crops with vegetables, evident in the villages of Govankoppa, Gongadikoppa and Maradagi (Table 4), and also on the Hubli *nalla* in the village of Gabbur. The larger the farm, the more land is devoted to field crops, as vegetable production generally requires greater labour inputs. A similar pattern was observed by Jansen et al.[(11)] in Vietnam, who found that vegetable crops required 2.5–6 times more labour than rice, which limited the amount of land that could be brought under vegetable production. Labour dynamics were not examined in the present study, so it is not possible to say whether the limits of intensive vegetable production were constrained by transport costs for these perishable products or availability of labour (as several farmers mentioned) or reliability of water flow or electricity supply. It is also noteworthy that most of the non-vegetable crops recorded in Table 4 are not staples (sorghum, rice, wheat) but arable crops sold for cash, indicating the priority accorded to financial income.

Beyond Maradagi, wastewater irrigation ceases and the cropping systems are rainfed, as during the dry season the quantity of wastewater flowing in the Dharwad *nalla* at this point is insufficient as a reliable source of irrigation. For field crops, such as cotton and wheat, wastewater irriga-

11. Jansen, H G P, D J Midmore, P T Binh, S Valasayya and L C Tru (1996), "Profitability and sustainability of peri-urban vegetable production systems in Vietnam", *Netherlands Journal of Agricultural Science* Vol 44, pages 125–143.

Table 5: Crop names: English, scientific and vernacular

Common name	Scientific binomial	Indian vernacular
Amaranthus (red)	*Amaranthus tricolor*	
Arecanut	*Areca catechu*	
Aubergine (eggplant)	*Solanum melongena*	Brinjal
Banana	*Musa paridasiaca*	
Beetroot	*Beta vulgaris*	
Cauliflower	*Brassica oleracea var. botrytis*	
Cabbage	*Brassica oleracea var. capitata*	
Chickpea	*Cicer arietinum*	Bengal gram
Chilli	*Capsicum annuum var. longum*	
Coconut	*Cocos nucifera*	
Coriander	*Coriander sativum*	
Cotton	*Gossypium herbaceum*	
Cucumber	*Cucumbar sativus*	
Curry leaf	*Murraya koenigii*	
Galimara	*Casuarina equisitifolia*	
Groundnut	*Arachis hypogaea*	
Guava	*Psidium guajava*	
Knol khol	*Brassica oleracea var. gongyloides*	
Lemon tree	*Citrus limon*	Nimbu
Mango	*Mangifera indica*	
Maize	*Zea mays*	
Mulberry	*Morus indica*	
Mungbean	*Vigna radiata*	Green gram
Napier grass	*Pennisetum purpureum*	
Neem	*Azadirachta indica*	
Okra (ladies' fingers)	*Abelmoschus esculentis*	Bhindi
Onion	*Allium cepa*	
Pomegranate	*Punica granatum*	
Ramphal	*Annona reticulata*	
Ridge gourd	*Luffa acutangula*	
Safflower	*Carthamus tinctorius*	
Sapota (sapodilla)	*Achras zapota*	Chuikku
Sorghum	*Sorghum bicolor*	Jowar
Spinach beet	*Beta vulgaris var.bengalensis*	
Tamarind	*Tamarindus indica*	
Teak	*Tectona grandis*	
Tomato	*Lycopersicon lycopersicum*	
Wheat	*Triticum aestivum*	

tion is used simply to start the field crop season earlier and when rainfall is initially erratic during the rainy season. This brings added advantages over purely rainfed agriculture, as the crops that are harvested earlier command higher market prices, as once the market is inundated with produce from rainfed systems the market prices tumble.

During the *kharif* season, the choice of vegetables grown is not based just on market demand but also on what is consumed within the household, whereas during the dry season market demand prevails and vegetables with high off-season prices are preferred, such as chillies (see Figure 3). If cotton is grown, planting takes place during the dry season in April, and sewage irrigation is used to start the crop before the *kharif* season.

The greatly increased incidence of weeds and pests found in the intensive vegetable production system applies equally to the system of field crops with vegetables. However, the nature of the cropping patterns and the increased distance from Dharwad results in different priorities for the farmers. As in the intensive vegetable production system, weed control in seasonal vegetable plots is based on hand tillage, although there is a notable shortage of labour to undertake the weeding. Farmers in the outlying villages do not have the convenience of being able to draw on the urban unemployed (as and when required) during peak periods, unlike their counterparts in Madihal. This shortage of labour is a constraint that is frequently mentioned by farmers in Govankoppa, Gongadikoppa and Maradagi, and it influences the decision by some farmers not to grow vegetables during the dry season, when lucrative prices can be fetched for such produce. On the other hand, weed control in field crops is more conveniently achieved by inter-row cultivation with draught animals.

f. Agroforestry

In India, wastewater-irrigated agroforestry has long been recognized as a strategy to dispose of urban wastewater, while also rehabilitating and greening wastelands.[12] In the peri-urban villages of Budarsingi and Katnur, on the main Hubli *nalla*, all farmers bordering the *nalla* engage in some kind of wastewater-irrigated agroforestry. In other areas, only sporadic planting of trees on farm boundaries and occasional agroforestry can be observed. The benefits of agroforestry include reduced irrigation requirements, and therefore reduced exposure of farmers to wastewater as, during the dry season, vegetable crops are irrigated every two days while tree crops are irrigated every ten days. Furthermore, farmers who have adopted an agroforestry system have reported a substantial increase in income from the produce.

12. See reference 5, Das and Kaul (1992).

In the villages of Budarsingi and Katnur, the main wastewater-irrigated agroforestry land uses are orchards and agrosilviculture which consists of spatially mixed tree–crop combinations. The two most important tree species are sapota and guava, and other common species are coconut, mango, arecanut and teak. Species found on farm boundaries include neem, tamarind, coconut and teak. Other less common species are banana, ramphal, curry leaf, pomegranate, lemon, galimara and mulberry. In agrosilviculture, field crops grown include irrigated groundnut in the dry season and sorghum in the *kharif*. Many adaptations of the agrosilviculture system were observed. Farmers in Budarsingi and Katnur villages also identified vigorous weed growth as the main constraint to agroforestry.

g. Fodder production

An additional wastewater irrigation system was observed near Maradagi. Since 1995, a small-scale dairy farmer has been irrigating a 0.4-hectare plot of Napier grass *(Pennisetum purpureum)*, alternating wastewater with borehole water on a daily basis. The grass is grown throughout the year and used as fodder for eight dairy cows and two bullocks stalled nearby. A supplement of rice bran is also fed to the livestock. The farmer reported that changing from dry feed to Napier grass fodder had produced an impressive two-fold increase in milk yield, from 3–4 litres per day to 8 litres per day.

13. Birley, M H and K Lock (2002), "Health and peri-urban natural resource production", *Environment and Urbanization* Vol 10, No 1, pages 89–106.

Photo 2: Farmer standing in flooded furrows while transplanting cauliflowers

IV. DISCUSSION

a. Health issues

THE USE OF sewage-contaminated wastewater has significant health implications for both the farmer and the consumer.(13) The wastewater is laden with faecal bacteria (Table 6) and, at worst, could expose the farmer to the risk of dysentery or even cholera. Crops are grown on ridges, but the farmers stand in the furrows in the flowing wastewater rather than risk damaging the ridges during vegetable transplanting and weeding operations, thus increasing their contact with and exposure to untreated wastewater (Photo 2). In a study carried out on the effects of wastewater on the health of 40 farmers from Madihal and Gabbur,(14) anaemia was identified as the *"…commonest finding and was related to nutritional deficiency and to worm infestation"*, but numerous symptoms of dermatitis were observed on the lower legs in 50 per cent of the sample. Admittedly, this study did have a small sample size and there was no control group, but it did highlight some of the health implications of wastewater irrigation.

The use of ridge and furrow irrigation rather than flood irrigation does not reduce the risk of crop contamination either. The results of an exploratory crop test at the University of Agricultural Sciences, Dharwad, showed that crop samples taken from a ridge were bacterially contaminated by the wastewater flowing in the furrow(15) (see Table 6). Boiling or other cooking at high temperature will kill faecal bacteria, but some crops, such

14. Hunshal, C S and K Sindhe (1997), "Wastewater: problems and opportunities: paper 10", in University of Agricultural Sciences, Karnataka University, SDM Engineering College, Dharwad, India, University of Birmingham, University of Nottingham and University of Wales, Bangor (editors), *Baseline Study for Hubli–Dharwad City Region, Karnataka, India,* Introductory Workshop on Peri-urban Production System Research Programme, July 1997, Natural Resources International.

15. Alagawadi, A R, professor of Agricultural Microbiology, University of Agricultural Sciences, Dharwad – personal communication 19 May, 31 May and 6 June, 2001.

Table 6: Surface and endo-microflora of sewage-irrigated crops				
Location and crop in field	Surface microflora (coliform units per gram of sample)		Endo-microflora (coliform units per gram of sample)	
	Total microflora	*E. coli*	Total microflora	*E. coli*
A_1 Aubergine	16.5 x 10^2	2 x 10^2	1,000	35
A_2 Aubergine	nil	nil	nil	nil
Z_1 Amaranth	165.5 x 10^2	nil	405	10
Z_2 Amaranth	160.0 x 10^2	nil	225	35

A = taken from ridge; Z = taken from basin; 1 = nearest to sewage source; 2 = furthest from sewage source. Samples taken 31 May 2001 from Madihal, Dharwad and tested at the Department of Agricultural Microbiology, University of Agricultural Sciences, Dharwad, under the supervision of Dr Alagawadi, professor of Agricultural Microbiology.

Note: values above 30 cfu/g of sample pose direct risks to human health if eaten raw. The lower *E. coli* counts obtained on the surface samples are due to sunlight exposure and desiccation killing the bacteria (Alagawadi, 2001).

as cucumber, are eaten raw. Furthermore, it is possible that boring pests (e.g. *Helicoverpa armigera*) that invade crop fruits (e.g. aubergine) on wastewater-irrigated fields are likely to increase bacterial contamination of the crop by providing additional entry routes.

Wastewater-irrigated crops grow very lushly and are very attractive to insect pests. The resultant intensive use of insecticides presents another health risk. Knapsack sprayers used as applicators are poorly maintained and often leak, the operators never wear any protective clothing and legs and hands are often bare, and concentrates are handled without any gloves or face masks (Photo 3). The net result is an increased risk of crop contamination and of farmers' exposure to pesticide poisoning. In India, farmers are well aware of the immediate toxic nature of pesticides; the 1984 Bhopal disaster and the oft-reported cases of farmers committing suicide through pesticide consumption serve as vivid reminders. Conversely, there is less general awareness of the cumulative effect of organophosphate pesticide poisoning, which often manifests itself in the gradual failure of the immune system, making it less detectable by health workers and epidemiologists.

Photo 3: Farmer mixing endosulphan insecticide concentrate with no protection

Furthermore, in a recent study in northern Karnataka, 20 per cent of drinking water supplies were found to be contaminated with endosulphan, an organochlorine pesticide that is commonly used in wastewater-irrigated vegetable production.[16] Inevitably, pesticides will persist as residues in crops in markets, but no samples were analyzed for this study.

16. See reference 7.

As mentioned above, most farmers have adopted some method for filtering the wastewater as it is pumped from the *nallas*. This rudimentary filtration is used to prevent soils from becoming clogged with plastics, disposable syringes and other debris. Several farmers along both *nallas* have reported the presence of disposable needles and syringes in the wastewater, with one farmer having seen an intravenous injection set in the *nalla*. In Govankoppa, a farmer complained of standing on needles buried in the soil – up to 20 times in a single day. In Katnur, a farmer displayed a disposable syringe and needle that had been recovered from the filter fitted to the wastewater inlet pipe (Photo 4). The foremost concern for these farmers is the cost of any medical treatment that would be required if infection did occur. In addition to raising regulatory issues regarding bio-medical waste control, these examples highlight the importance of farmers taking action themselves, through fitting rudimentary filters to the wastewater inlets.

Photo 4: Hypodermic syringe and needle recovered by a farmer from the filter fitted to the wastewater inlet pipe

b. Gender implications of wastewater irrigation

Regardless of the cropping system being used, the high nutrient loading from wastewater greatly increases the incidence of weeds and, as mentioned, farmers also attribute this to seeds that are carried in the wastewater and then pumped onto the fields. Consequently, as the main weed control method is hand tillage, weeding accounts for the high labour inputs associated with wastewater-irrigated cropping systems. Household members supply these labour inputs and, within the household, women normally carry out these tasks. Likewise, when farm labourers are hired, they are more likely to be women, due to the cheaper labour costs. Census data also confirm that a higher proportion of women are engaged in urban agriculture. The male population seize mainly non-farm opportunities, as wages are higher than in the agricultural sector. (Building labourers earn 80 rupees per day as opposed to farm labourers who earn 60 rupees).[17] The primary role of women in urban agriculture perpetuates their position as the poorest social group. Furthermore, working full days in the fields increases their exposure to the hazards of wastewater and, once the day's work is finished, the women return to their households and carry out evening chores, including food preparation and cooking, thereby increasing the risk of pathogen transfer to other family members if basic standards of hygiene are not maintained.

17. Budds, J and A Allen (1999), *Peri-urban Profiles: Hubli–Dharwad, India*, Research Paper, Development Planning Unit, University College London; also Hillyer, K J, A Patil and C S Hunshal (2002), "Annex B: a study of the livelihood strategies of the poor and very poor in peri-urban areas of Hubli–Dharwad and the impact of urbanization upon them", in Brook (2002), see reference 7.

c. Management of irrigation with wastewater

Wastewater irrigation of field crops with vegetables is not going to go away and, as mentioned above, as the water supply to Hubli–Dharwad improves, it will most likely increase significantly.[18] The outright banning of wastewater irrigation would be neither practical nor feasible and, in addition, for urban and peri-urban farmers the economic implications of such a measure would be vast. A comparison of vegetable yields from wastewater and borehole-irrigated fields revealed a 20–25 per cent yield advantage from wastewater irrigation, although the additional variable costs incurred due to high weed and pest infestation were not determined. Many of these farmers own small plots of land, and growing irrigated vegetables provides a viable means of earning a living for them and for any farm labourers they employ. Although their economic conditions prior to growing vegetables were not determined, farmers owning small plots of land tend to be poor, so intensive vegetable production may be one route out of poverty.

As noted in section 1.2 of the Hyderabad Declaration on wastewater use in irrigated agriculture: "*…[w]ith proper management, wastewater use contributes significantly to sustaining livelihoods, food security and the quality of the environment.*"[19] Environmental services which result from the wastewater irrigation of vegetables, as suggested by Midmore and Jansen, include the treatment of sewage, the decreased use of landfill sites if solid organic municipal waste is utilized (which it is not in the case of vegetables around Hubli–Dharwad, although it is on cash arable crops) and the provision of green spaces in urban areas.[20] Certainly, in the case of Hubli–Dharwad, sewage contamination of watercourses effectively ceases from beyond 10 kilometres from the city, but only during periods of intensive pumping.

Therefore, achieving a "proper management" approach is vital if public health and environmental risks are to be mitigated without threatening the livelihoods of poor farmers. Some authors argue for a decentralized approach to wastewater management,[21] and this surely is part of the solution to the hazards arising from these practices. However, the key to early advances in management lies in education. In Hubli–Dharwad, centralized or decentralized wastewater treatment systems are unlikely to be implemented in the near future; therefore farmers irrigating with wastewater should be encouraged and supported to adopt safer and more sustainable farming practices. A change from the current reliance on chemical pesticides to integrated pest management strategies, and a conversion to agroforestry practices, will require long-term support through participatory approaches such as the use of farmer field-schools which empower farmers through education and training in sustainable agricultural practices. Experience in more recent projects in Hubli–Dharwad has shown that involving non-governmental organizations in mobilizing the farming community into self-help groups is a promising way to facilitate such learning.[22] The particular nature of the farming systems along the Dharwad and Hubli *nallas*, and the complex nature of integrated pest management, suggest that a village-based extension approach is likely to be the most suitable. The public health benefits of such an approach could also be enhanced through public education aimed at raising awareness of disease prevention through better food-handling, preparation and cooking practices.

18. See reference 1.

19. IWMI and IDRC (2002), "The Hyderabad Declaration", *Urban Agriculture Magazine* Vol 8, No 4.

20. Midmore, D J and H G P Jansen (2003), "Supplying vegetables to Asian cities: is there a case for peri-urban production?", *Food Policy* Vol 8, pages 13–27.

21. Parkinson, J and K Tayler (2003), "Decentralized wastewater management in peri-urban areas in low-income countries", *Environment and Urbanization* Vol 15, No 1, pages 75–89.

22. Halkatti, Meera, Sangeetha Purushothaman and Robert Brook (2003), "Participatory action planning in the peri-urban interface: the twin city experience, Hubli–Dharwad, India", *Environment and Urbanization* Vol 15, No 1, pages 149–158; also Brook, Robert (2003), "Partnerships in research and development in the peri-urban interface around Hubli–Dharwad, India", poster presented at the conference on Global Forum for Agricultural Research, Dakar, Senegal, 22–23 May, 2003.