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Farmers' perceptions and knowledge in using wastewater for irrigation at twelve peri-urban areas and two sugar mill areas in Bangladesh

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ABSTRACT

By interviewing farmers in twelve peri-urban and two sugar mill areas information was collected on the use of urban wastewater. In all cases, untreated sewage water was used without primary treatment. The domestic polluted water originated from household kitchen, cloth wash, bathroom shower, and other municipal sources (e.g., supermarkets, restaurants, offices). Moreover it was often diluted by urban storm-water drainage. Major quality parameters of the wastewater were determined. The boron, iron, sodium, nitrogen, phosphate and zinc content along with the electrical conductivity and pH of the wastewater, with few exceptions, were lower than their safe limits for irrigation. The manganese content always exceeded the recommended threshold limit. Most farmers irrigated rice (*Oryza sativa* L.), and, in few locations, potato (*Solanum tuberosum* L.), wheat (*Triticum aestium* L.) and vegetables (e.g., tomato; *Lycopersicon esculentum* L.) with wastewater. At one peri-urban area, farmers stopped irrigating with wastewater after having (free) access to freshwater. The farmers at another area were very concerned of its negative impact on human and soil health. Because of high temperature and impurities, only few farmers used wastewater for irrigating sugarcane (*Saccharum* sp. L.) and rice by diluting it during the scarcity of freshwater at one sugar mill area, and only some tail-end farmers directly used it for irrigating rice at the other area. In this manuscript, the word 'wastewater' refers to 'untreated sewage water'. In Bangladesh, water treatment is rare.

Farmers articulated two opposing attitudes for irrigating with wastewater. They recognized fertility, reliability and low cost of wastewater in one extent, and viewed, as negative elements, the presence of solid wastes, fecal matter, engine oil, grease, diesel, molasses, and harmful chemicals in the other extent. Also the social acceptability of wastewater was low. While working with wastewater, farmers faced multi-facet problems of blistering, skin infection, injury to hands and lower legs, bad smell, mosquito nuisance and damage to low-lift pumps due to solid wastes. Important considerations for preferring wastewater were to avoid high cost of pumping groundwater and to save on chemical fertilizers. Also, farmers did not perceive any problem with the quality of the yield. The farmers strongly felt a necessity of primary treatment of wastewater to remove solid wastes, heavy ones by settling and suspended ones by separation, before irrigation. Although aware of the fertility value of wastewater, most farmers lacked knowledge on how to adjust its doses. All these demonstrated a necessity of proper policy, training, and more information on health precautions as well as on food safety in using urban wastewater.

1. Introduction

Bangladesh is an agrarian country where 84% of its population live in rural areas and are engaged in a wide range of agricultural activities accounting for 62% of the countries' labour force (BBS, 2004). The country has 8.3 Mha (million hectare) of cultivable land of which 7.0 Mha are potential area for irrigation. However, only 4.48 Mha is covered by irrigation systems and 2.52 Mha remains out of irrigation due to shortage of water (BBS, 2004). Agriculture is the largest user of water at global level since irrigated agriculture currently consumes 70% of the world's developed freshwater supplies (Gleick, 2000; FAO, 2001); in some low-income countries, irrigation consumes 95% of all water uses. Pereira et al. (2002) reviewed different options for the development of irrigation, such as more efficient use of water or use of alternative sources of water, and suggested using treated wastewater when freshwater is scarce. Huibers and van Lier (2005) agreed with Pereira et al. (2002) and added producing freshwater from non-conventional water sources, such as sea water/brackish water and active harvesting of atmospheric water as additional options to increase water for irrigation.

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Pescod (1992) described the controlled use of urban wastewater as a contributor to water conservation and food production. A wider recognition is now being given to wastewater as an important resource in many countries. Irrigation with wastewater has become a common practice in peri-urban areas. At the advent of increased scarcity of freshwater in Bangladesh, low quality water warranted attention for further development of irrigation by coping with water shortage. The major sources of low quality water in the country include arsenic-polluted water, urban and industrial wastewater, and saline water. The densely populated cities in the country receive, on priority, almost all the water they need and 70% of which returns as waste. According to van Rooijen et al. (2005), the rapidly growing cities along with improved water supplies can easily double the wastewater flow in few years' time due to mounting use of water and also its control disposal. The Economic and Social Commission for Asia and the Pacific (ESCAP, 2000) reported an annual production of 725 Mm^3 of wastewater from the urban areas of Bangladesh. So, it is plausible and convincing that the use of this water for irrigation can be integrated in a holistic approach for the management of water quantity and quality. Well-planned utilization of wastewater in agriculture will increase food production by more irrigation coverage and improve the livelihood of farmers at the proximity of wastewater sources. As reported by Shuval et al. (1986), such utilization of wastewater can promote incentives for local people to operate and maintain local systems, and help to ensure long-term operation and financial sustainability.

One major problem in low-income countries is that the treatment of wastewater is not a priority. The practice of re-using untreated wastewater for irrigation might, in the longer term, also be an important incentive towards treatment. Qadir et al. (2010) advocate a stepwise approach to exploit local opportunities rather than trying to achieve "foreign" (*sic*; meant here are high-income countries) standards. However, it will be quite important to devise a treatment which has the agricultural re-use as a primary objective. Achieving good hygienic conditions with low or no suspended solids while preserving the nutrients in the wastewater should be a major objective towards use for irrigation (Jiménez et al., 2010). This is in contrast to the more ecologically oriented goals in richer countries, which try to avoid eutrophication of the rivers and water bodies by lowering nitrogen and phosphorus during treatment. The safe use however remains as a major challenge (WHO, 2006).

Traditional irrigation prefers to use good quality water in order to increase crop yield, ensure yield quality, maintain soil productivity, protect the local environment and preserve groundwater quality. The users of low quality water may therefore face multifacet problems since its use in irrigation can degrade soil and groundwater quality due to biological and chemical contamination with subsequent adverse effects on crop production as well as on human and animal health (Bruvold and Crook, 1981). A detailed knowledge of these problems is a pre-requisite for any step to move forward in using low quality water for irrigation. Before suggesting wastewater use or any solution to the linked problems, information on wastewater use and attitudes of the public towards it are necessary. This is because, as Hartley (2006) found, managing information for all, maintaining organizational and personal commitment, promoting public dialog, building trust and sound decision-making are crucial in shaping the perception and nature of public participation in the use of wastewater. The use of untreated sewage water for irrigation by peri-urban farmers is not yet well documented in Bangladesh. The aim of this study was therefore to assess the challenges of using untreated wastewater for irrigation based on farmers' knowledge and perceptions on this issue. The objectives were: (i) to know the current status of wastewater use by farmers, (ii) to identify the problems and challenges faced by the farmers in irrigating with wastewater, and (iii) to assess farmers' perception and knowledge on the use of wastewater in irrigation. The results of this study should contribute to a better definition of training needs for farmers and to a better identification of research priorities.

The term 'wastewater' has been used differently in the literature to mean different stages of polluted water. Generally, it signifies any water that has been adversely affected in quality by anthropogenic influence. We use 'wastewater' to refer to the untreated/raw municipal wastewater/urban wastewater that contain a broad spectrum of contaminants resulting, mainly, from the mixing of wastewaters from household kitchen, cloth wash, bathroom shower, and runoff from rainfall. The sewage water in Bangladeshi cities is normally collected in open or semi-covered drains, which also serve at the same time for storm-water evacuation. The contamination includes various solid wastes (e.g., plant residues, kitchen garbage, shopping polyethylene bags), and often feces or urine from the sides of the drain. Sugar mill factories discharge large amounts of wastewater with high levels of organic material, sugar, lubrication oil and grease. The pH is variable as occasional washing and cleaning of machinery is executed. Most often, pH is alkaline. In addition, the temperature of the discharged water from the sugar mills is elevated.

2. Methodology

A structured questionnaire was developed to know farmers' perceptions on wastewater and current scenario of its use in agriculture in twelve peri-urban areas and two sugar mill areas. The questionnaire included questions to identify the attitudes and knowledge of the farmers concerning the use of wastewater for irrigation. It addressed the cropping patterns, farm inputs (water, pesticides, fertilizers) and outputs (yield), irrigation practices (water sources, methods), impacts of wastewater irrigation on local environment and health, and farmers' attitudes in using wastewater for irrigation. Using the questionnaire, a farmer-survey was executed in the peri-urban areas of Bogra, Chittagong, Comilla, Dhamrai, Gazipur, Jamalpur, Khulna, Kustia, Mymensingh, Rajshahi, Sherpur and Sylhet towns, and along the wastewater canals of Pabna sugar mill at Pabna and North Bengal sugar mill at Natore. The target populace, aged between 25 years and 55 years, were the adult farmers involved in irrigation using wastewater. Their literacy limit varied between illiterate and intermediate level; the majority belonged to the illiterate group. Farmers were selected randomly from the target group and interviewed following the questionnaire. Some employees of the Pabna sugar mill were also interviewed. It is noted that the number of farmers interviewed varied from 15 to 53 within the 14 locations. This was due to the fact that at some locations, only a limited number of farmers was directly involved in irrigation using wastewater. Also, most of the farmers being poor engaged themselves in other income-generating activities, such as small business, in addition to their farming activities. So, it was difficult to get access to many farmers to keep the sample size large and uniform at all the locations. In addition to the questionnaire survey, wastewater samples of ten peri-urban towns (out of the twelve surveyed) were collected and analyzed for their chemical properties. The major parameters included boron, iron, potassium, manganese, sodium, nitrogen, phosphate, zinc, electrical conductivity and pH. For the wastewater at Mymensingh, cadmium, copper and lead content were also determined. The water quality parameters were measured in the laboratory at a constant temperature of $25 \pm 1\,^{\circ}C$ using a HACH DR/890 colorimeter (Hach Company, P.O. Box 389, Loveland, Colorado, USA) and a CD230 conductivity meter (Radiometer Analytical SAS, 72 rue d'Alsace, 69627 Villeurbanne CEDEX, Lyon, France).

The wastewater in most of the peri-urban regions consists of the polluted water from the domestic sources (hereafter referred to as

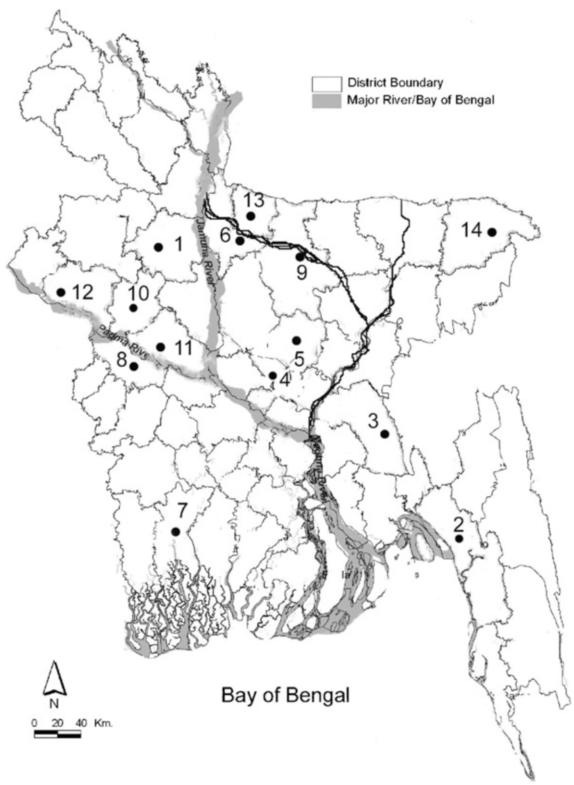

Fig. 1. Map showing the locations of twelve peri-urban areas and two sugar mill areas where field survey was conducted. (1) Bogra; (2) Chittagong; (3) Comilla; (4) Dhamrai; (5) Gazipur; (6) Jamalpur; (7) Khulna; (8) Kustia; (9) Mymensingh; (10) Natore (sugar mill); (11) Pabna (sugar mill); (12) Rajshahi; (13) Sherpur and (14) Sylhet.

domestic wastewater), such as kitchen wash, cloth wash, bathroom shower, other municipal sources (e.g., supermarkets, restaurants, offices), and runoff from rainfall; toilet flush is separately diverted to underground septic tanks. The wastewater thus generated is referred to as municipal/urban wastewater. The municipal wastewater is disposed off, usually, through open road-side drains. These drains also evacuate storm water. Consequently, plant residues, kitchen and road-side garbage, and often urine and fecal matter are flushed by the runoff water; especially during the monsoon period. In one peri-urban location, industrial wastewater also adds to the municipal wastewater. Water treatment, even primary settling of solids, is very rare in Bangladesh.

The study locations, as marked in Fig. 1, were distributed over most part of Bangladesh and thus represent the major peri-urban areas of the country. Bangladesh is a country of rivers and most cities and towns are established on river banks. Since many rural people along the banks use river water for bathing, washing and often domestic purposes, most of the municipal wastewater is diverted to the in-land water bodies through drainage canals; in most cases a part of the wastewater is also discharged to the river. The major part of industrial wastewater in large cities is drained to the nearby rivers and the remaining is discharged to other small in-land water bodies. In selecting the locations for the survey, emphasis was given to the peri-urban areas in the proximity of drainage canal carrying wastewater where farmers were either irrigating with this water or there were farming communities with irrigable lands. Out of fourteen locations surveyed, only three (Dhamrai, Natore, Pabna) have predominant industrial wastewater, and the remaining produced only domestic wastewater.

The information collected through the survey was tabulated both in terms of positive and negative perceptions of the farmers on the use of wastewater in irrigation. The positive viewpoint included crops irrigated with wastewater and their yield, and contribution of wastewater to crop and soil fertility. The negative viewpoint was focused on disease and health problems, and impacts on crop growth and local environment due to irrigation with wastewater. Additionally, based on the perceptions on wastewater irrigation, the farmers were quantified at Rajshahi and Mymensingh. These analyses included determining the degree of motivation and problems faced by the farmers, and their view on local environment due to irrigation with wastewater. During questionnaire survey, farmers at these two locations provided more specific opinions on the quantity of fertilizer they use and also on the quantity of yield of common crops that they harvested. So, variance of the data sets under the two irrigation water quality regimes was also analyzed. The level of significance at which the two data sets differed significantly was determined. No detail data could be collected for cost-benefit analysis of the irrigated farming, partly because the farmers could not provide specific information on their investment in the farming activities. So, the economic aspects of the irrigation were evaluated only qualitatively. However, field experiments are being done with wheat and potato under irrigation with water of different qualities to quantify various aspects of irrigation with wastewater including the cost-benefit characteristic.

3. Results and discussion

3.1. Aspects of irrigation with urban drainage water

3.1.1. Motivations for irrigation with wastewater

The matter of choice is an important determinant to the public acceptance of using wastewater. Some recognizable points iden-

Table 1
Summary of wastewater irrigation and farmers' perception at different locations in Bangladesh.

Districts/locations	No. of sample farmer	Crops irrigated with wastewater	Wastewater-irrigated area (ha)	Fertility of wastewater	Yield quantity
Bogra	35	Rice, potato, potato, ginger and local vegetables	47–67	Fertile	Increased, often decreased
Chittagong	25	Rice, cauliflower, cabbage, tomato and spinach	Not known	Fertile	Increased
Comilla	30	Rice	20–27	Fertile	No idea
Dhamrai	50	Rice	67–80	Fertile	Decreased
Gazipur	31	Rice	27–33	Mixed idea	Increased/decreased
Jamalpur	20	–	Not known	No idea	–
Khulna	15	Rice	Not known	No idea	Increased, often decreased
Kustia	20	–	Not known	No idea	–
Mymensingh	53	Rice	Not known	Fertile	Increased
Natore (sugar mill)	15	Sugarcane, rice	Not known	No idea	No idea
Pabna (sugar mill)	15	Sugarcane, rice, wheat, radish, carrot, cauliflower, cabbage and tomato	Not known	No idea	No idea
Rajshahi	52	Rice, wheat potato, maize, cabbage, cauliflower, papaya, spinach and local vegetables	27–33	Fertile	Increased
Sherpur	15	Rice	27–33	Mixed idea	Increased/decreased
Sylhet	40	Rice	267–334	No idea	Decreased

Table 2
Degree of motivation of farmers and problems faced by them in using wastewater for irrigation at Rajshahi and Mymensingh; the number of sample farmers was 52 at Rajshahi and 53 at Mymensingh.

Elements of motivations	% respondents		Type of problems	% respondents	
	Rajshahi	Mymensingh		Rajshahi	Mymensingh
Source of fertilizer	92	74	Itching and skin blistering	79	87
Low cost, easily available	77	25	Injury to hands and legs	10	13
High crop yield	88	47	Odd smell	42	47
High cropping intensity	37	0	Damage to pump	21	8
Improves soil quality	67	43	Leech attack	17	72
No other water source	2	58	No problem	10	11

tified as reasons for using wastewater in irrigation at different locations of Bangladesh are summarized in Table 1. While farmers at some locations were not aware of fertility value of wastewater, they were well aware of it at other locations. Farmers irrigated with wastewater since it reduced production cost by saving fertilizers. Another motivation was that crops grew well when irrigated with wastewater and resulted in higher yield compared to that irrigated with freshwater. Because of high cost of chemical fertilizers, farmers very often applied low doses, which reduced yield. As compared in Table 2, 92% farmers at Rajshahi and 74% at Mymensingh mentioned that irrigation with wastewater added fertilizer to the land. At Mymensingh, 58% farmers irrigated with wastewater for not having access to freshwater. Such use of wastewater, also reported by Raschid-Sally et al. (2005), was typical by the poor people in peri-urban areas without having access to freshwater and for whom wastewater was their only possible input. Because of increasing awareness of persistent water shortage in some places, people articulated their interest in using wastewater. Because of its availability the year around, 37% farmers at Rajshahi achieved high cropping intensity by irrigating with wastewater; some farmers produced three crops a year. Farmers irrigating with wastewater earned more than those irrigating with freshwater because of the reliability of fertile wastewater round the year at no or low cost. The rent of land with access to wastewater was also higher than that without this access. Some farmers at Rajshahi had access to both fresh- and wastewater sources, but preferred using the latter because of its fertility value. They uttered making movement against any initiative to divert wastewater from their access. Few farmers were even willing to pay for getting wastewater. Sixty seven percent farmers at Rajshahi and 43% at Mymensingh believed that fertility of their lands increased gradually due to irrigation with wastewater. The motivation of using wastewater in irrigation thus showed that it was not just merely related to water scarcity only.

Urban wastewater was not in the consideration of the peri-urban farmers of Jamalpur for its use in irrigation. They regarded this water as a worthless waste. The city of Jamalpur is on the bank of a large perennial river called the Brahmaputra. The local aquifer has a good reserve of groundwater and is developed with borehole wells. The peri-urban farmers, like others, used river water as well as groundwater for irrigating rice, wheat and vegetables. While not being aware of any positive aspects (fertility, cheap or free, reliability) of wastewater they were very concerned of its negative impacts on soil quality, and human and animal health due to its poor quality. There was "yuck factor" or disgust in psychological terms as used to study public attitudes towards wastewater use (Melbourne Water, 1998; Kaercher et al., 2003; Po et al., 2003) among the farmers. The perceptions of peri-urban farmers at Kustia on wastewater use were mostly similar to those at Jamalpur. In the past, some farmers irrigated vegetables with wastewater but stopped the practice later when they got better access to freshwater for irrigation. The Kustia city is within the command area of the Ganges-Kobadak surface water irrigation project run by the government of Bangladesh, and the peri-urban farmers have access to irrigation water from the project. It is noted that most of these farmers, however, diverted water for irrigation from the project canal, but evaded project authority of any payment for water. The yuck factor, as identified among the farmers, was mostly prevalent when they had alternatives to wastewater and also they were not much aware of any beneficial aspects of using wastewater.

3.1.2. *Farmers' view in wastewater quality*

Major chemical constituents of the untreated wastewater, such as boron, iron, potassium, manganese, sodium, nitrogen, phosphate, zinc, electrical conductivity and pH of ten municipal locations are compared in Table 3. These quality variables were closely comparable between different locations since the urban

Table 3
Important chemical properties (average of 3 samples) of municipal wastewater at different districts of Bangladesh along with the FAO (1992) recommended threshold (TV) values of these parameters. Bold underlined values exceed the TV.

Districts/locations	Average chemical constituents of wastewater (mg l^{-1})								EC (dS m^{-1})	pH
	B	Fe	K	Mn	Na	NO_3-N	PO_4-P	Zn		
Bogra	0.43	0.41	6.52	**<u>0.4</u>**	49	2.4	7.9	0.01	0.53	6.88
Chittagong	1.31	0.98	7.54	**<u>0.3</u>**	50	3.1	**<u>17.9</u>**	ND	**<u>0.71</u>**	6.81
Comilla	0.06	0.25	5.23	**<u>0.3</u>**	52	2.4	4.8	0.01	0.55	6.88
Dhamrai	0.51	0.33	5.87	**<u>0.6</u>**	59	1.7	**<u>10.4</u>**	0.02	0.59	7.4
Gazipur	0.17	0.47	5.68	**<u>0.3</u>**	49	2.1	9.9	ND	0.63	6.98
Khulna	0.05	0.29	5.12	**<u>0.4</u>**	60	2.7	5.3	ND	**<u>0.72</u>**	6.85
Mymensingh	0.69	0.23	7.43	**<u>0.4</u>**	54	4.2	3.7	0.02	**<u>1.05</u>**	7.33
Rajshahi	0.37	0.43	7.71	**<u>1.1</u>**	49	4.4	**<u>15.0</u>**	ND	**<u>1.02</u>**	6.54
Sherpur	0.09	0.37	4.21	**<u>0.5</u>**	50	3.0	6.3	0.01	0.39	6.62
Sylhet	0.10	0.12	4.89	**<u>0.3</u>**	44	5.1	0.2	0.02	0.09	**<u>5.43</u>**
TV	3.00	5.00	–	0.2	69[a]	30.0	10.0	2.00	0.70[b]	6.5–8.5

ND: not detectable.
[a] Moderate restriction for irrigation starts at 3 mequiv/l or 69 mg/l.
[b] This is an average value. Actually, threshold values of EC is dependent on sodium adsorption ratio (SAR) as: for the SAR value of 0–3, 3–6, 6–12, 12–20 and 20–40, the corresponding threshold value of EC (dS m^{-1}) is 0.2, 0.3, 0.5, 1.3 and 2.9.

wastewater was almost entirely generated from domestic water uses. Considering the quality criteria of irrigation water, manganese (0.3–1.1 mg l^{-1}) content of the wastewater at all locations was higher than its recommended threshold value (0.2 mg l^{-1}; FAO, 1992). Of the other constituents, only phosphate at Chittagong, Dhamrai and Rajshahi, and electrical conductivity at Mymensingh and Rajshahi exceeded the recommended (average) threshold values (Table 3). For short-term (20 years) irrigation practice, the lower limit of the threshold phosphorus content is 25 mg l^{-1}. The electrical conductivity actually acts interdependently with sodium adsorption ratio (SAR) and, therefore, it increases with the increasing SAR as given in Table 3. Cadmium, copper and lead content of wastewater at Mymensingh were 1.35, 0.3 and 0.8 μg l^{-1}, respectively; these concentrations were substantially lower than the threshold values (10, 200 and 5000 μg l^{-1}, respectively). In rich countries, the reduction of nitrogen, phosphorus and potassium (NPK) in wastewater is necessary before releasing it into water bodies as to avoid eutrophication. But, in poorer countries like Bangladesh, NPK form the valuable source of fertilizers when untreated wastewater is used in irrigation. Taking into account the chemical properties of the urban wastewater, it is affirmed that this water has a good potential for using in irrigation, preferably with a little pre-treatment. Currently, there is no treatment of the wastewater in practice. Since urban wastewater contained considerable quantities of major fertilizers (nitrogen, phosphorus and potassium) and the farmers irrigating with this water did not properly account for or even ignored that, excessive growth with lodging of the crops often reduced the yield.

There was an attention-grabbing angle in farmers' perceptions on the quality of wastewater. While speaking generally about quality, the farmers termed urban wastewater as 'bad water'. They found oily substances, solid wastes, fecal matter, harmful chemicals, etc. in wastewater. As listed in Tables 2 and 4, skin blistering, bad smell, often injury to legs and hands, and damage to water lifting pumps were the major problems faced by the farmers during application of wastewater and working in the irrigated fields. Farmers at Chittagong reported an additional complaint of diarrhea as a result of working with wastewater. Extermination of fish and other aquatic habitats in the wastewater canals was also common at some locations. Focusing on cost-effective crop production, most farmers acknowledged considerable fertilizer content in wastewater and gave favorable opinion on the suitability of wastewater for irrigation. The farmers thus express two opposing views in their perceptions towards the quality of wastewater: repugnance in the family and social spheres, and valuable in the economic sphere. Although the farmers could not quantify the fertilizer contribution of wastewater, most of them applied it at reduced but varying rates. The farmers at all but Khulna peri-urban locations experienced luxuriant growth of their crops (Table 4) under irrigation with wastewater with occasional insect/pest attacks and reduced yield. They possessed contrasting perceptions on the quality of soils irrigated with wastewater—some acknowledged continuous increase of soil fertility while others recognized degrading soil quality due to irrigation with wastewater. Farmers at most locations strongly felt a necessity of low or no cost primary treatment of wastewater to get rid of solid wastes before applying it for irrigation. Like other regions in Bangladesh, the farmers at the peri-urban areas extracted groundwater for domestic use mostly by manually operated borehole wells, popularly known as (deep set) hand tubewells. These tubewells generally penetrated one or more clay layers before reaching the extractable groundwater aquifer. None but only one farmer at Mymensingh experienced deteriorated quality of drinking water extracted from below a wastewater-irrigated field. However, this observation with domestic wastewater is not appropriate in the industrial areas for which national newspapers often reported quality problems of extracted groundwater. Of the farmers at Rajshahi and Mymensingh, over 90% applied reduced fertilizer dose under irrigation with wastewater but still they recognized increasing soil fertility. They were at odds in estimating insecticide requirement – one half of them applied reduced quantity and the other half did not reduce the rate. In spite of their current involvement in irrigation with wastewater, some of them uttered skepticism in irrigating with wastewater apprehending undesirable impacts on soil health in the long run. In instances where an alternate water source, such as a near by borehole well or a river, was available, people questioned the need for using wastewater. Such thoughts and attitudes of the farmers again implied that the yuck factor was closely related to the availability of freshwater sources. Indeed, when the option of using wastewater was discussed, most farmers stated that there had to be a genuine need for using it. They stressed that it should be considered only after

Table 4
Perceived negative impacts of wastewater irrigation on health, crops and environment by the farmers at different districts/locations in Bangladesh.

Districts/locations	Diseases/health problems	Other problems	Impacts on local environment
Bogra	No disease	Excessive vegetative growth of crops	Fish in wastewater receiving river
Chittagong	Diarrhea, skin blistering, irritation, bad smell	Often excessive vegetative growth of crops	Fish cannot survive in wastewater canal
Comilla	No disease, irritation, bad smell	Excessive vegetative growth of crops	Fish in wastewater canal
Dhamrai	Skin blistering, irritation, bad smell	Excessive vegetative growth of crops	No aquatic life in Bangshai river due to industrial wastewater, soil health degrading
Gazipur	No disease, bad smell	Excessive vegetative growth of crops	Not felt
Jamalpur	Disease in imagination, bad smell	–	Negative impacts in aphrenhension
Khulna	No disease, irritation, bad smell	Often tidal saline water enters the wastewater canal	Saline wastewater degrades soil health
Kustia	Bad smell	–	Negative impacts in aphrenhension
Mymensingh	Skin blistering, irritation, injury to hands and legs, odd smell, mosquito nuisance	Damage to pumps, leech problem, excessive vegetative growth of crops	Fish in wastewater canal, soil fertility increased
Natore (sugar mill)	Skin blistering, odd smell, mosquito nuisance	High effluent temperature, suspended solid, oil and grease in effluent	Degrade soil fertility, destroys aquatic life, often degrades groundwater quality
Pabna (sugar mill)	Skin blistering, odd smell, mosquito nuisance	High effluent temperature, suspended solid, oil and grease in effluent	Degrade soil fertility, destroys aquatic life, often degrades groundwater quality
Rajshahi	Skin blistering, irritation, injury to hands and legs, bad smell	Damage to pumps, leech problem, excessive vegetative growth of crops	Few people culture fish in wastewater ponds, soil fertility increased
Sherpur	No disease, irritation, bad smell	Often excessive vegetative growth of crops, pest attack	Soil fertility increased
Sylhet	Skin blistering, irritation, bad smell	Excessive vegetative growth of crops	Fish cannot survive in wastewater canal

other solutions were impractical—a mental setting very similar to that reported by Bruvold and Crook (1981).

3.1.3. Crops and irrigation practices

The farmers at the peri-urban locations irrigated rice as the main crop with wastewater (Table 1). They used wastewater in irrigating potato, ginger and local vegetables at Bogra, cauliflower, cabbage, tomato and spinach at Chittagong, and wheat, potato, maize (*Zea mays* L.), cabbage, cauliflower, papaya (*Carica papaya* L.), spinach and local vegetables at Rajshahi. The farmers at Rajshahi irrigated leafy vegetables with wastewater at priority since high N content of this water provided good growth of leaves. In contrast, the farmers at Mymensingh used wastewater in irrigating rice only because of suitability of their land for this crop. These farmers were doubtful of the hygienic safety of vegetable crops if irrigated with wastewater and hence of any scope of their marketing. The farmers at all locations cultivated transplant rice during monsoon (August–November) under rain-fed conditions; occasional supplemental irrigation was needed. The peri-urban farmers often plugged the drainage canal carrying wastewater by constructing small earthen dams to head up water for gravity diversion. Those belonging to the low lying area irrigated their crops under gravity flow while those at the high land area pumped water from the canal by a low-lift motorpump. Few farmers irrigated manually with buckets and swing baskets. The farmers having high land thus spent some extra money in getting wastewater to their crop fields.

3.1.4. Fertilizer management

Although many farmers recognized the fertility values of wastewater, they had inadequate insight into it and applied fertilizers at rates based on mind's eye. They generally applied higher quantity than actually necessary in order to avoid the risk of low yield due to inadequate fertilizer. Some farmers, without giving any significance to the fertility value of wastewater, did not take into account the nitrogen (N) content of irrigation water for determining the fertilizer requirement of the crops. They frequently obtained reduced yield of rice due to excessive vegetative growth and lodging of the plants (Table 4). The excessive growth occurred in the fields mostly located at the head end of the canal where wastewater first entered the field. This indicates that a rice-field has potential as a shallow open surface water lagoon for primary water treatment. The farmers at the far/tail end of the canal seldom faced the problem of excessive growth since some water-born fertilizers had settled as it passed over some distance. Some farmers reported obtaining excessive growth of paddy even after applying only half the amount of urea that they applied in fields irrigated with freshwater. The inappropriate fertilizer management was due to the fact that the fertilizer content of wastewater had not been quantified and the farmers did not have any means/scope to do that. There was also not any specific recommendation on fertilizer rate under wastewater irrigation. They applied various fertilizers based on their superficial needs, mostly acquired from years of experience. A contrast on fertilizer application for cultivating some common crops under irrigation with wastewater and freshwater at Mymensingh and Rajshahi is given in Table 5. It is noted that although farmers had years of experience on fertilizer application, they had very little knowledge of its balanced use. Most farmers at Mymensingh used only urea because of its low price compared to the triple super phosphate (TSP) and muriate of potash (MP). Only a few farmers used TSP and MP along with urea at rates lower than that needed under irrigation with freshwater. The farmers at Rajshahi, on the other hand, knew better about fertilizer management than those at Mymensingh. Realizing the fertility contribution of wastewater they applied one-third to half the recommended dose of TSP and urea. Currently fertilizers' price is at 55% subsidized rate in Bangladesh. If 50 kg of TSP (roughly one-third of the recommended dose) is saved per crop and per hectare using wastewater, then a farmer saves around 2000 Taka (~200 Euro) and the government a slightly higher amount. To prevent excessive vegetative growth and lodging of the crops, the farmers often applied an additional amount of MP. However, only a few farmers, both at Mymensingh and at Rajshahi, used fertilizers as per requirement taking into consideration the contribution from wastewater; some did not apply certain fertilizers while others applied more than the required quantity. The application rate of urea was significantly ($p < 0.05$) lower in the fields irrigated with wastewater for rice and potato, but not for wheat, than in the fields irrigated with freshwater. There was, however, no significant difference in the rate of other fertilizers between the two irrigation water quality regimes except that the rate of MP was significantly low in case of wheat irrigated with wastewater.

3.1.5. Crop yield and yield quality

The peri-urban farmers articulated mixed experiences on the quantity of crop yields obtained under irrigation with wastewater; the majority of them reported getting increased yield (Table 1). The peri-urban farmers at Rajshahi and Mymensingh claimed getting significantly ($p < 0.05$) higher yield of rice, wheat, potato and maize grown under irrigation with wastewater than the yield of these crops grown under irrigation with freshwater. Because of inappropriate fertilizer application some farmers at Mymensingh obtained reduced yield of rice; excessive vegetative growth caused lodging and reduced yield. The farmers did not recognize any problem with the quality of yield produced with wastewater except that only a few farmers at Mymensingh made non-specific complaints of low quality of rice. The quality aspect of the yield produced under irrigation with wastewater reported herein was, however, not conclusive since crop samples were not analyzed.

3.1.6. Cost of irrigation with wastewater

Due to high cost of pumping, irrigation with fresh groundwater was costlier than that with wastewater at the peri-urban locations.

Table 5
Rate of fertilizer use (kg ha^{-1}) for rice, wheat and potato cultivated under irrigation with wastewater (WW) and freshwater (FW) at Rajshahi and Mymensingh, and significance level (SL) at which the quantity of fertilizer under two irrigation water regimes differs significantly.

Fertilizers	Fertilizer use and crop yield (kg ha^{-1}) at											
	Mymensingh for			Rajshahi for								
	Rice irrigated with			Rice irrigated with			Potato irrigated with			Wheat irrigated with		
	WW	FW	SL*	WW	FW	SL	WW	FW	SL	WW	FW	SL
Urea	94	178	0.01	234	298	0.05	403	588	0.01	403	588	0.01
MP	12	22	0.05	102	80	0.30	188	294	0.15	188	294	0.15
TSP	16	34	0.00	138	78	0.05	148	252	0.60	148	252	0.60
Yield	6132	5642	0.045	4552	3976	0.023	3218	2322	0.003	3852	3274	0.031

* The significance level (SL) was analyzed by Tukey's HSD (Honestly Significant Difference) test in the R-package at 5% level of significance.

The water charge for organized irrigation schemes varies from 7500 to 22,000 Taka (75–220 Euro) per hectare. In the dry months (February–April), the groundwater level dropped and most suction lift pumps, popularly known as shallow tubewells (STW's), stopped pumping and others pumped at a much lower (often <50%) rate than their capacity causing a shortage of freshwater in many locations. More reliable but also more expensive is a Deep Tube Well (DTW). Farmers irrigating with wastewater did not face the problem of such water scarcity since the flow of wastewater was steady. Some of these farmers possessed low-lift pumps (LLPs) and pumped wastewater at a much lower cost than pumping groundwater with borehole wells (STW's and DTWs). Other farmers having no LLPs in their ownership paid a small amount for pumping wastewater. As mentioned before, farmers irrigating with wastewater also spent less on fertilizer.

3.1.7. Problems of working with wastewater

The major problems that farmers faced in working with wastewater (Tables 2 and 4) included blistering and skin infection, injury to hands and legs, atrocious smell, and damage to pump due to solid wastes (added to the wastewater from the road-side garbage during runoff from rainfall); attack of leeches was also extensive in wastewater. Plastic items, broken rubber sandals/shoes, and shopping polyethylene bags were the major solid wastes that the farmers encountered in wastewater. All farmers complained of itching and blistering at hands and lower legs as the most appalling problem. Some farmers at every location also complained of physical injury to hands and legs from sharp objects in wastewater like needles, blades, broken glass, etc. Therefore, the response of the farmers generally agreed with the statement 'I have no objection to recycling of water as long as safety is guaranteed' as found in the study of Jeffrey and Jefferson (2002) in the United Kingdom. Thirty seven percent farmers at Rajshahi and 39% at Mymensingh experienced itching and skin blistering after working with wastewater. There was more of a problem of mosquitoes at Mymensingh than at Rajshahi. Like the respondents in the study of Sydney Water (Po et al., 2003), when the farmers were asked what they thought of the disadvantages of using wastewater, the most commonly mentioned statements were related to health concerns. Although considered helpful, poor farmers could not afford to use rubber boots and hand gloves to protect them from harmful materials while working with wastewater. Instead, they often used socks, which they made from used cloths. Sometimes they also rubbed kitchen oils (e.g., mustard and soybean oils) and even fuels (kerosene, diesel) as a measure to protect the exposed skins of their hands, feet and lower legs before entering the crop fields irrigated with wastewater.

3.2. Farmers' view on wastewater of sugar mills

There were 15 sugar mills in Bangladesh that produced sugar along with large quantity of wastewater (1000 l/ton of crushed cane) from floor washing and condensate. Leakage in valves and glands of the pipelines added sugarcane juice, syrup and molasses in the wastewater. The wastewater had a high biological oxygen demand (BOD) of 1000–1500 mg l^{-1}. The major quality variables of concern of the wastewater were the temperature, pH, BOD, total soluble solid (TSS), chemical oxygen demand (COD), engine oil and grease (Khwaja and Quraishi, 2003). Initially, the wastewater appeared clean, but it turned black and started emitting a foul odor after stagnation for sometime. Initial temperature of the wastewater was high, and when discharged in water bodies it depleted their dissolved oxygen and made the environment unsuitable for aquatic life. All the wastewater of these two sugar mills in this study is firstly collected into a small pond, which overflows into a wastewater drain. The ponds are too small to contribute to substantial treatment apart from some settling of solids.

The farmers irrigated sugarcane, rice, jute, wheat and vegetables (radish, carrot, cauliflower, cabbage, tomato, etc.) at the adjacent areas of the Pabna sugar mill, but only sugarcane and rice at the North Bengal sugar mill area at Natore (Table 1). At Pabna sugar mill area, crops were irrigated with groundwater that was extracted from bore holes with STWs. Due to poor quality of the sugar mill wastewater, the farmers rarely used it for irrigation. There was considerable quantity of oily substances along with other impurities including molasses in the wastewater. The farmers in the other sugar mill area also reported similar impurities in the wastewater. Farmers' claim of these problems were substantiated by the occasional presence of oily spots on the land surface along the wastewater canal during the field survey that was executed after five rainy months of stopping operation of the mills. Akbar and Khwaja (2006) reported adverse impacts of oil, grease and other pollutants in the wastewater on crop yields. The high temperature of the wastewater was a major problem to the farmers since it completely damaged the crops when used for irrigation. In the dry months (March–April), the discharge of STWs decreased due to declining groundwater level in the Pabna sugar mill area. Some farmers then used the wastewater of the sugar mill for irrigation by mixing it with groundwater at 1:1 ratio. These farmers realized that such mixing of wastewater with freshwater diluted impurities and reduced wastewater temperature to a tolerable level. A severe problem in the Pabna sugar mill area was the uncontrolled disposal of wastewater due to inadequate drainage system. The wastewater very often entered the land and damaged 25–50 ha crop land every year. In general, sugar mills' wastewater contained either acidic or alkaline compounds, a considerable concentration of suspended solids and sugar with a high BOD and COD concentrations. Such highly concentrated wastewater creates substantial problems. An anaerobic treatment with bio-gas production and heat-exchange could be an option, that at the same time, can provide cheap energy to the factory. Farmers realized that the organic solids, oil and grease in the untreated wastewater clogged the soil pores upon entering the land. The wastewater degraded soil fertility, destroyed aquatic life, and often degraded groundwater quality. It thus created human and animal health hazard by polluting the local environment. The Environmental Technology Program reported similar problems of using wastewater in irrigation for Industry (ETPI, 2001) in Pakistan. Ecological degradation was also reported in Thailand where the Mae Klong river receiving wastewater from 12 sugar mills damaged ecology due to extensive killing of fish, and adverse impacts on cockles and shrimp breeding areas. That river began recovering after installation of a treatment plant in late seventies (UN ESCAP, 1982). At the Natore sugar mill area, the wastewater passed through a long distance with a subsequent drop in temperature. Some tail-end farmers then directly used this water for irrigating rice. The farmers at both sugar mill areas faced the problems of odd smell and mosquito nuisance. They also complained of skin blistering due to working in the fields irrigated with the wastewater.

4. Conclusions

The peri-urban farmers of twelve locations and the proximate farmers of two sugar mills possessed mixed knowledge on the use of wastewater for irrigation. The farmers at most locations realized the contribution of wastewater to fertilizer and its availability round the year at low/no cost, and hence they irrigated field crops with this water. Although the farmers had a strong awareness of the fertility value of wastewater, they lacked knowledge on how to adjust fertilizer doses. Some farmers (at Kustia) used wastewater only because they did not have access to freshwater. They stopped the use of wastewater once they had access to freshwater.

The farmers at one peri-urban area (Jamalpur) were yet not aware of any beneficial aspect of wastewater while they were extremely concerned of its negative impact on health. The wastewater of the sugar mills had high temperature and contained impurities including engine oil, diesel and molasses. Only few farmers at one location used the wastewater in irrigation after mixing it with freshwater while some tail-end farmers at the other location directly used the wastewater for irrigation. It is noted that while some farmers faced water shortage due to lack of access to freshwater sources, some faced water shortage due to their inability to pay for it. The water shortage led the farmers to search for secure but cheap water sources. Wastewater then becomes attractive. The urban wastewater was discharged into natural drains that increased availability of wastewater at the downstream areas. The downstream farmers thus found an option to irrigate with this water irrespective of the overall level of water scarcity.

Crop production was cheaper under irrigation with wastewater. Freshwater requires a high pumping cost and a larger amount of chemical fertilizers. Although farmers generally viewed wastewater unfavorably, they did not perceive quality loss of the harvest due to wastewater. Farmers at all peri-urban and sugar mill locations faced the problems of odd smell, skin infection (itching and blistering), injury to hands and legs, and damage to water lifting pumps (due to solid wastes added to the wastewater from the road-side garbage with runoff water) during irrigation with wastewater. The farmers felt a strong necessity of primary treatment of wastewater to remove solid wastes before using it in irrigation. Some training and information on health precautions as well as on food safety were therefore felt necessary. The boron, iron, sodium, nitrogen, phosphate and zinc content of the urban wastewater along with its pH and electrical conductivity were below their recommended threshold levels for irrigation except for the phosphate content at 3 locations. The manganese content always exceeded the threshold levels for safe use. Only farmers at some locations raised concern that irrigation using wastewater might degrade soil health in the long-term.

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