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Impact of the Bangshi River Water Quality on Irrigated Soil and Rice in Bangladesh

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Abstract: This study was conducted to investigate the impact of water quality of the Bangshi River, a part of the Bangshi-Turag system in the north-central (NC) region of Bangladesh, on irrigated soil, and growth and yield performances of rice (BRRIdhan-29) by selecting a polluted site (PS) and a pollution free control site (CS) along the river. Water and soil samples from both sites were collected on different growing stages of rice and analyzed on spots and in laboratories following standard methods and instruments. Growth and yield parameters of rice from both sites were collected through measurements and surveys in the rice fields and farmers' households. The results of the study revealed that the values of pH, EC, DO, Cl, NH_4-N, SAR, Cu, Fe, Mn, Pb, Cd, Ni and Cr in river water exceeded the safe limits for irrigation at the PS, whereas these parameters were within the safe limits at the CS. The contents of most nutrients (except B) as well as metals in soil were found to be higher at the PS than those of the CS. However, the most growth and yield parameters of rice (except the weights of unfilled/damaged grains and rice husks) were significantly lower at the PS than those of the CS, which might be due to the irrigation with water polluted mostly by untreated industrial effluents.

Key words: Bangshi River, water quality, irrigated soil, growth and yield performances of rice, polluted and control sites, untreated industrial effluents.

Introduction

Bangladesh is an agrarian and a riverine country. The overall economic performance of the country depends on agriculture which contributes 21.1% to Gross Domestic Product, of which 72% is contributed by crop sector (MoF, 2007). Rice covers about 70% of the total cropped area and constitutes about 92% of the annual food grain production in the country. Rice is the major user of irrigation water covering 82% of the total irrigated area in Bangladesh (Rashid et al., 2005). Ground water is the main source of irrigation water in Bangladesh, which contributes 80.6% of the total irrigated area (BADC, 2007a). The river system contributes to the rest particularly during the dry season (November-May). The quality of river water is indispensable because irrigation with poor quality water has detrimental effect on irrigated soil, plant growth and yield of rice (Abbas et al., 2007; Begum, 2006; El-Sharkawi et al., 2004; Rahman, 2006; Reddy and Behera, 2006). However, the river water, used by the people of rural Bangladesh for irrigation and other purposes during the dry season, is now vulnerable to pollution due to seasonal variation of river flow, increased human interventions from urbanization and industrialization, over use of chemical fertilizers and pesticides in irrigated farms, etc. Concerns of river water quality deterioration are gradually emerging, particularly in the North-Central (NC) part of the country, due to the

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disposal of mostly untreated industrial effluents to the rivers.

The Bangshi River, a part of the Bangshi-Turag system in the NC region of Bangladesh, was once an important source of water for drinking and domestic uses, fisheries, agriculture, etc. However, the river is now vulnerable to increased pollution during the dry season from industrial and municipal wastewater mostly from the Dhaka Export Processing Zone (DEPZ) and other planned and unplanned industrial clusters in and around Savar area. About 71% of textile industries in Savar area produce untreated effluents of about 4800 m^3 per day which are finally drained to the Bangshi River through local canals (DoE and BEMP, 2004a). Furthermore, the dry season flow of the river has decreased because of siltation, increased upstream withdrawal, etc., which have increased the pollution intensity and decreased the self cleaning capability. Though the surface water becomes scarce during the dry season and the cost of irrigation with ground water is high, local cultivators of Dhamrai upazila (small administrative unit) located at the north-western part of Dhaka city still use this polluted water for rice cultivation. But this water has resulted in severe losses to traditional agriculture in terms of soil fertility, plant growth and yield of rice as revealed from the reconnaissance survey of the local farmers.

Though a number of studies (DoE and BEMP 2004b; Rahman and Hossain, 2008) have investigated the impacts of water pollution of some rivers of the NC region such as the Buriganga, Shitalakhya, Dhaleshwari, Balu and Turag, neither was on the Bangshi River nor on the impact of polluted water on soil quality and rice yield. So, this study made an endeavour to investigate the impact of water quality of the Bangshi River on irrigated soil, plant growth and yield performances of BRRIdhan-29 during the 2007-2008 *boro* season. The specific objectives were (i) to assess the status of water quality of the Bangshi River and the quality of the soil irrigated with this river water; (ii) to estimate the changes in the growth and yield performance of rice, and (iii) to find out the causes of the changes in the growth and yield performance of rice.

Materials and Methods

Study Area

The Bangshi River takes off from the foot of the Madhupur Tract and flows through the Tangail district and travels southward to fall into the Dhaleshwari River after entering Dhaka district near the junction of Kaliakoir and Savar upazilas of Gazipur and Dhaka districts, respectively. The total length of the river is 184 km and it has a basin area of 1077 km^2. The river works as the central spine for drainage of the NC region of Bangladesh. The river is fed partly from the Jamuna River through the northern Dhaleswari intake via the Pungli River, partly by the accumulated runoff of Jhenai and Fatikjani Rivers from the north-west, and partly by direct runoff from the western slopes of the Madhupur Tract (Figure 1).

This study was conducted by selecting two study sites, one is pollution affected Kulla union (Site I or polluted site) at the downstream part and the other is pollution-free Sombhag union (Site II or control site) at the upstream part along the Bangshi River of Dhamrai upazila. Site I receives industrial effluents mostly from the DEPZ and the other planned and unplanned industrial clusters in and around Savar area, whereas the Site II is more or less free from this pollution. Irrigation water and irrigated soil quality of Site II were considered as control conditions to estimate the impact of contaminated irrigation water on irrigated soil, growth and yield performance of rice at Site I. The irrigation schemes of Site I and Site II were operated mostly by the farmer cooperatives of Kaijarkundu and Makhulia villages, and Goaldi and Kashipur villages, respectively. The BRRIdhan-29 was the dominant variety of rice at both

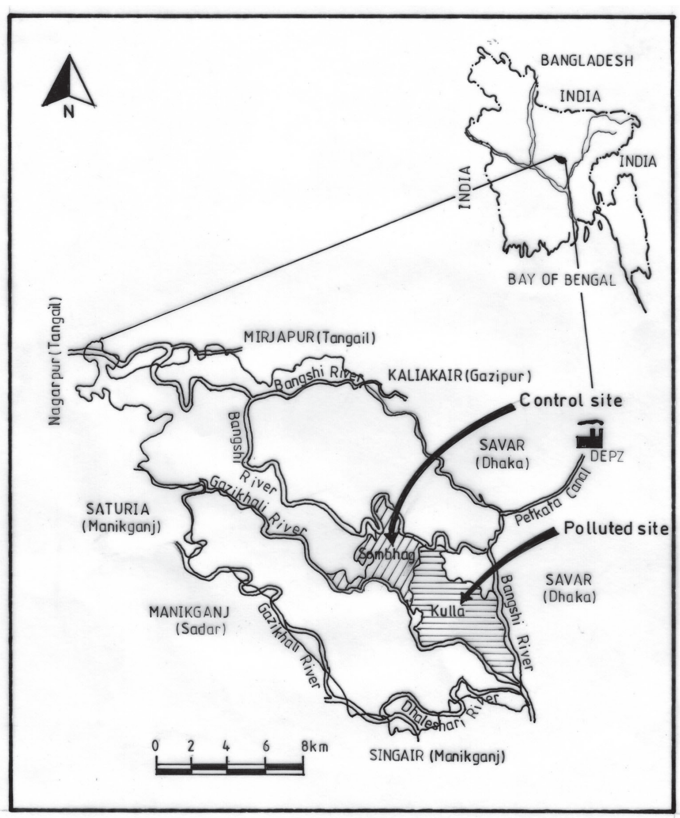

Figure 1: Location of the polluted (site I) and control (site II) sites.

sites. The growing period of this variety was 135 days in both sites. The mode of irrigation at both sites was low lift pumps (LLPs). The climate of both sites is similar and is characterized by low temperature in the months of December-January and high temperature in the months of April-May. The average rainfall in the winter (November-February) and pre-monsoon (March-May) seasons are 72 mm and 515 mm, respectively (SRDI, 2002). The study sites fall under the same Agro-Ecological Zone namely the Young Brahmaputra-Jamuna Floodplain. The typical cropping pattern of the area is mustard-rice-fallow. The farming practices are almost similar at both sites during 2008-2009 *boro* season.

Collection of Water and Soil Samples

This study was conducted during the *boro* season of 2007-08. Two water sampling sites along the Bangshi River and two soil sampling sites on the co-operative river water irrigation schemes at Site I and Site II were selected by taking into account the processes affecting water quality and their influences. The span of life of the cultivated rice variety was divided into three growth stages namely vegetative, reproductive and ripening stages. The subsequent 45 days from the initial transplanting date were considered for each growth stage of rice. Water and soil samplings were carried out at the vegetative (34 days after transplantation (DAT)) and reproductive (75 DAT) stages because the mortality of rice seedlings, rotting of roots, etc., were seen at these stages in the rice field of Site I. Moreover, polluted irrigation water has profound impact at the vegetative and reproductive stages in terms of growth and yield performance of rice (Zeng et al., 2001; Wang et al., 2001; Hassan et al., 2005).

A total of three irrigation water samples, two from Site I, each at the vegetative and reproductive stages and one from Site II at the reproductive stage of rice, were collected. One water sample was collected from Site II because quality of water is always good and local people use it for bathing, washing, cooking and irrigation purposes. New plastic bottles with hard plastic screw caps were used for water sample collection. The bottles were properly cleaned before using and washed 2-3 times with the river water to be stored before sampling. Water samples were collected from midstream by dipping each sample bottle 20-30 cm below the water surface, opening the bottle and allowing it to fill in and closing with its cap under water (Jaji et al., 2007; UNEP/WHO, 1996). Each water sample was collected in two bottles, placed in an ice box and transported to the laboratory on the same day. After transfer, one bottle was filtered using Whatman filter paper (125 mm diameter) and acidified with 2 ml nitric acid to prevent the precipitation of heavy metals. The two samples were then preserved in a refrigerator at about 4°C until analysis.

Two irrigated soil samples from Site I and one sample from Site II were collected from the plough depth (0-15 cm) on the same day of water sample collection. The soil samples were collected following Bangladesh Agricultural Research Council (BARC, 2005) guidelines. During the soil sample collection from each site, the irrigated rice fields were considered as a single plot and nine sampling points were demarcated in that plot. Soil sample from each point was collected by digging a ‘V’ shaped hole up to the plough depth with a clean country spade, taking a slice of soil having almost uniform thickness from one of the vertical side of the hole and placing on a plastic sheet. The sub-samples were sized by discarding excess soil from both the sides of the slice and plough pan at the bottom, and freed from stubbles, grasses, plant roots, etc. After that, the sub-samples were mixed thoroughly and made a composite sample for that plot. The composite sample was divided into four piles over the plastic sheet, two piles were discarded, the remaining two piles were mixed again and the process was continued until the weight of the sample was about 500 g. Then the sample was dried in a shaded place and pulverized with pestle. The sample was taken finally to the laboratories for analysis.

Analysis of Water and Soil Samples

Water from the non-filtrated and non-acidified bottle was used for analysis of a wide range of water quality parameters, including Cl, NH_4-N, Na, Ca and Mg, within a week. Water from the filtrated and acidified bottle was used for analysis of heavy metals, including Cu, Fe, Mn, Zn, Pb, Cd, Ni, Cr and As. pH, EC and DO of irrigation water were measured on sites by using portable pH meter, EC/TDS meter and digital oxygen meter, respectively. Cl of water samples was measured by titrimetric method (Huq and Alam, 2005) and NH_4-N by colorimetric method with Nessler’s reagent (Ramesh and Anbu, 1996). Ca and Mg were determined through Atomic Absorption Spectrometer (AAS) and Na by Flamephotometer (Petersen, 2002). Heavy metals, such as Cu, Mn, Pb, Cd, Ni, Cr and As, of water samples were determined by both Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) (Aydinalp et al., 2005) and AAS, whereas Fe and Zn were analyzed by using AAS (Petersen, 2002). The sodium absorption ratio (SAR) of irrigation water was calculated from the ratio of Na ions and squared root of Ca and Mg ions’ average.

Soil texture was determined from sieve and hydrometer analysis. EC and pH of soil were measured in a 1:5 and 1:2.5 soil-water suspension using Metrohm 644 conductivity meter and Metrohm 691 glass electrode pH meter, respectively (Petersen, 2002). OM was determined by Walkley and Black's method and CEC by ammonium acetate extraction method (Huq and Alam, 2005). The concentrations of Ca and Mg were determined through AAS, and K by Flamephotometer from soil extraction done by using ammonium acetate extracted solution (Petersen, 2002). The content of N was measured by Kjeldahl method, P by Olsen's method, S by calcium biphosphate extraction method and B by calcium chloride extraction method (Petersen, 2002). The concentrations of heavy metals, such as Cu, Fe, Mn, Zn, Pb, Cd, Ni and Cr, were determined by DTPA extraction method through AAS (Petersen, 2002), whereas As was determined by nitric acid digestion method through AAS (Saha and Ali, 2007). Water and soil samples were analyzed by using the laboratory facilities of Bangladesh University of Engineering and Technology, Soil Resources Development Institute and Bangladesh Council of Scientific and Industrial Research, Dhaka.

Collection of Data on the Growth and Yield Parameters of Rice

Growth and yield parameters of rice from both sites were collected through measurements in the rice fields and surveys at farmers' households. Data on plant height, root length, panicle length, tillers per plant and grains per panicle were collected from different plots of the rice fields randomly before harvesting of rice. Information on yield of rice grains, problems exposed in the rice fields, unfilled grains, rice husks and straw yield were collected through surveys and measurements at household level after the harvest of rice. Sample size for household survey was calculated by trial and error method using the standard equation of Haan (1977). Total number of households at Site I and Site II were 308 and 65, of which 60 households from Site I and 20 from Site II were surveyed by using structured questionnaire, though the equation gave a total of 37 and 18 samples for Site I and Site II, respectively. Processed (dried and cleaned) grain samples of rice were collected in separate plastic bags from farmers' houses of the study sites randomly for measuring the weight of 1000 grains. Total 25 grain samples were collected from Site I and 10 from Site II, and finally determined the weight of 1000 grains from each sample by using digital weight meter.

Results of the Study

Water Quality of the Bangshi River

The results of water sample analysis are shown in Table 1. It is seen from the table that the values of pH, EC, Cl, NH_4-N, Na, SAR, Cu, Fe, Mn, Zn, Pb, Cd, Ni, Cr and As of both water samples at Site I were remarkably higher than those of Site II. On the other hand, the values of DO, Ca and Mg in both water samples were significantly lower at the polluted site than those of the control site. The lower DO level in sample 1 compared to the sample 2 at the polluted site was likely due to the higher temperature in water and the increased plant growth and decay during this period (Ahonkhai and Chukwuogo, 1996). The level of DO at the polluted site directly helps realize the intensity of pollution of the river during the dry season. The lower concentrations of Ca and Mg at Site I might be due to the precipitation effect of higher pH (Tripathi and Govil, 2001).

The average values of pH, EC, Cl, NH_4-N, Na, SAR, Cu, Fe, Mn and Ni at the polluted site were determined to be about 1.3, 5.6, 5.2, 16.3, 62.4, 107.4, 6.9, 6.7, 7.0 and 5.5 times higher than those of their respective values at the control site, and Zn, Pb, Cd, Cr and As were below the detection level at the control site. On the contrary, the average concentrations of DO, Ca and Mg at the polluted site were about 5.1, 2.9 and 3.4 times lower than those of their respective concentrations at the control site. The values of pH, EC, DO, NH_4-N, SAR, Cu, Pb and Cd of the samples 1 and 2; Mn and Cr of the sample 1; and Cl, Fe and Ni of the sample 2 at Site I were found to be exceeding the irrigation water quality standards. The concentrations of Na, Ca, Mg, Zn and As of both samples at Site I were within the safe limits. In contrast, all of the water quality parameters at Site II were found to be within the safe limits for irrigation. According to the irrigation water classification on the basis of EC levels (Wilcox, 1955), the water at the polluted site falls under the doubtful class for irrigation (EC = 2-3 dS/m) whereas it falls under the good class (EC = 0.25-0.75 dS/m) at the control site. Another irrigation water classification, on the basis of SAR values (BADC, 2007b), also shows that the water quality was bad (SAR > 26) at the polluted site whereas it was excellent (SAR ≤ 10) at the control site for irrigation purpose.

Soil Quality of Study Sites

The textures of the soils were determined to be silty clay loam (SCL) for all soil samples at both sites (Table 2).

Table 1: Water quality of the Bangshi River near Dhaka during the 2008-09 dry season

Parameters	*Unit*	*Polluted site*			*Control site*	*Irrigation water quality standards*	
		Sample 1	*Sample 2*	*Average*	*Sample 3*	*Bangladesh*[1]	*FAO*[2]
Field condition							
pH		9.53	9.76	9.65	7.4	6.0-8.5	6.5-8.4
EC	dS/m	2.48	2.65	2.57	0.46	2.25	NA
DO	ppm	0.8	1.2	1.0	5.1	≥ 5.0	NA
Laboratory condition							
Cl	ppm	553	618	585.5	112	600	NA
NH_4-N	ppm	11.4	14.6	13.0	0.8	3.0	NA
Na	ppm	594	529	561.5	9.0	1000	NA
Ca	ppm	22.0	22.0	22.0	63.5	NA	NA
Mg	ppm	6.4	7.0	6.7	22.5	NA	NA
SAR		28.7	25.0	26.85	0.25	23	NA
Cu	ppm	0.28	0.27	0.275	0.04	0.2	0.2
Fe	ppm	0.44	3.85	2.15	0.32	1-2	5.0
Mn	ppm	0.23	0.18	0.21	0.03	NA	0.2
Zn	ppm	0.05	0.177	0.12	BDL	5.0	2.0
Pb	ppm	0.21	0.37	0.29	BDL	0.10	5.0
Cd	ppm	0.11	0.03	0.07	BDL	0.1	0.01
Ni	ppm	0.06	0.38	0.22	0.04	0.5	0.2
Cr	ppm	0.12	0.08	0.1	BDL	NA	0.1
As	ppm	0.05	0.06	0.055	BDL	0.1	0.1

Note: [1]BADC (2007b); [2]Ayers and Westcot (1994); BDL = Below detection limit; NA = Not available.

Table 2: Results of the basic parameters of the studied soils

Study sites	*Sample No.*	*Textures*				*pH*	*EC*	*OM*	*CEC*
		Sand (%)	*Silt (%)*	*Clay (%)*	*Class*		*dS/m*	*%*	*C mol/kg*
Polluted site	Sample 1	13	50	37	SCL	6.0	1.45	2.08	18.72
	Sample 2	13	53	34	SCL	6.0	0.39	2.08	15.66
	Average	13	51.5	35.5	SCL	6.0	0.92	2.08	17.19
Control site	Sample 3	12	56.5	31.5	SCL	5.9	0.22	1.88	13.86

The pH levels of both soil samples at the polluted site were slightly higher than that of the control site. According to the soil classification on the basis of pH (BARC, 2005), the levels of pH at both sites were found to be slightly acidic (pH of 5.6-6.5) in nature. The values of EC, OM and CEC of both soil samples at the polluted site were higher than those of the control site. The salinity level in soil decreased abruptly from the first to the second sample in the case of the polluted site. This might be due to the excessive leaching of electrolyte concentration to the subsurface layer of soil (Emdad et al., 2004). According to the soil salinity classification (Gupta and Gupta, 1987), the soils of both sites were non-saline (EC < 2 dS/m) in nature. In terms of soil classification based on OM and CEC (BARC, 2005), the OM contents were found to be medium (OM of 1.8-3.4%) in all soil samples whereas the CEC levels were high (CEC of 16-30 meq/100 g soil) at the polluted site and medium (7.6-15 meq/100 g soil) at the control site. The average values of soil pH, EC, OM and CEC at the polluted site were determined to be about 1.02, 4.18, 1.11 and 1.24 times higher than those of their respective values in the control site.

The contents of nutrients in the soil samples are presented in Table 3. It is seen from the table that the contents of nutrients in both soil samples of the polluted site were higher than those of the control site, except for B. The B concentrations of both soil samples were lower at the polluted site than that of the control site, which might be due to the higher percentage of clay particles in soil samples at the polluted site (Table 2) as reported by Khandelwal and Lal (1991).

According to the nutrient status in loamy to clayey soils of wetland rice crops in Bangladesh (BARC, 2005), the concentrations of Ca, Mg and S in both soil samples at the polluted site were very high, whereas they were very high, optimum and low, respectively, at the control site. The contents of N and P were low and very low, respectively, in soil samples of the study sites, and the concentrations of K and B were optimum and medium, respectively, at the polluted site whereas both of them were medium at the control site. Moreover, the nutrient contents of soil samples of all the study sites were found to be higher than critical limits for loamy to clayey soils of wetland rice crops in Bangladesh, except for the N and P (BARC, 2005). The average concentrations of N, P, K, S, Ca and Mg at the polluted site were about 1.1, 1.2, 1.4, 5.2, 1.2 and 2.8 times higher than those of their respective concentrations of the control site (Table 3). On the other hand, the average B concentration of soil samples at the polluted site was about 0.9 times lower than that of the control site. The concentrations of heavy metals are shown in Table 4. It is seen from the table that the concentrations were higher in the second sample compared with those of the first sample, except for the Fe and Mn, in the case of the polluted site. However, the average concentrations of Cu, Fe, Mn, Zn, Pb, Cd, Ni, Cr and As at the polluted site were about 1.7, 2.9, 1.6, 1.1, 2.3, 36.3, 3.0, 2.5 and 171.8 times higher than those of their respective concentrations at the control site. Moreover, the concentrations of Fe and Ni in soil samples at the polluted site exceeded the maximum allowable limits of heavy metals in soils (Table 4). Therefore, the accumulation of heavy metals in soil due to the irrigation with polluted water is clearly evident at Site I.

Observed Problems in the Rice Fields

The farmers' surveys revealed that different types of problems had emerged in the rice fields at the polluted site but none of them were seen by the farmers of the control site (Table 5). Among the seven problems seen in soil at the polluted site, two problems (S_1 and S_2) were found to be during the vegetative stage, four problems (S_3, S_4, S_5 and S_6) were detected during both vegetative and reproductive stages, and the remaining problem (S_7) was observed all over the growing seasons. Among the 11 problems observed in rice plants at the polluted site, three problems (P_1, P_2 and P_4) were found to be during

Table 3: Status of macro- and micro-nutrients in soil samples

Nutrients	*Unit*	*Polluted site*			*Control site*
		Sample 1	*Sample 2*	*Average*	*Sample 3*
N	%	0.104	0.104	0.104	0.095
P	ppm	4.40	5.90	5.15	4.30
K	C mol/kg	0.29	0.29	0.29	0.21
S	ppm	80.96	106.90	93.93	18.00
Ca	C mol/kg	13.22	14.10	13.66	11.50
Mg	C mol/kg	4.06	2.42	3.24	1.17
B	ppm	0.32	0.37	0.35	0.40

Table 4: Metal concentrations in the soils irrigated with the water from the Bangshi River

Parameters	*Polluted site*			*Control site*	*Maximum allowable limits in soils*[1]
	Sample 1	*Sample 2*	*Average*	*Sample 3*	
Cu (ppm)	4.51	7.64	6.08	3.54	100
Fe (ppm)	453.6	410.4	432.00	147.2	300
Mn (ppm)	122.0	87.2	104.60	64.4	NA
Zn (ppm)	2.16	2.40	2.28	2.04	300
Pb (ppm)	17.8	26.25	22.03	9.75	100
Cd (ppm)	0.1	2.08	1.09	0.03	3
Ni (ppm)	47.5	54.20	50.85	16.95	50
Cr (ppm)	34.9	43.95	39.43	15.80	100
As (ppm)	4.11	9.63	6.87	0.04	20

[1]*Source:* Breemen and Moormann (1978); Kloke (1980); Sauerbeck (1985).

Table 5: Problems emerged in the rice fields at the PS irrigated with the water from the Bangshi River

Problems in	*Problem number*	*Description of problems*	*Time of occurrence of problems (DAT[1])*
Field soil	S_1	Colour of surface soil changed to black	5-30
	S_2	Soil became weak (sloth)	15-30
	S_3	Algal development	20-75
	S_4	Colour of soil surface became white after drying	10-60
	S_5	Number of pests increased	20-60
	S_6	Prevalence of weeds	20-85
	S_7	Increased mosquitoes	Entire growing period
Rice plant	P_1	Rotting of roots	3-30
	P_2	Mortality of seedlings	3-30
	P_3	Leaf colour became red	30-75
	P_4	Plants grew rapidly	1-40
	P_5	Problem of panicle initiation	50-60
	P_6	Mortality of panicles	60-90
	P_7	Rotting of roots of matured plants	45-70
	P_8	Mortality of rice plants	45-90
	P_9	Rice plants fell on the ground	55-65
	P_{10}	Colour of panicles changed to black	60-75
	P_{11}	Colour of leaf changed to black	60-65

[1]DAT is days after transplantation

the vegetative stage, one problem (P_3) during the first two stages and the remaining seven problems (P_5, P_6, P_7, P_8, P_9, P_{10} and P_{11}) were observed during the middle of the growing period (reproductive stage). It is also observed that vegetative and reproductive stages were found to be more vulnerable in terms of soil related problems, whereas reproductive stage was found to be more vulnerable in terms of plant related problems at the polluted site.

Growth and Yield Parameters of Rice

The growth and yield parameters of rice are shown in Table 6. The average plant height, root length and panicle length were smaller in the polluted site compared with those of the control site. The grain yield was found to have positive relationships with the number of tillers per plant, grains per panicle, weight of 1000 grains and straw yield. All of these parameters were found to be lower at the polluted site compared with those of the control site resulting in higher amount of unfilled grains and rice husks at the polluted site. The plant height, root length, panicle length, tillers per plant, grains per panicle, weight of 1000 grains, unhusked and husked grain yield, and straw yield were found to be about 21.9, 33.3, 23.8, 42.1, 45.0, 15.4, 30.3 and 41.9, and 30.8% lower and the unfilled/damaged grains and rice husks were about 107.5 and 36.8% higher at the polluted site than those of the control site, respectively.

Table 6: Growth and yield parameters of rice irrigated with the water from the Bangshi River

Parameters	*Unit*	*Polluted site*	*Control site*
Plant height	cm	76.20	97.54
Tillers per plant	No.	11.00	19.00
Length of root	cm	15.24	22.86
Length of panicle	cm	20.32	26.67
Grains per panicle	No.	88.00	160.00
Weight of 1000 grains	g	19.63	23.21
Unhusked grain yield	t/ha	4.32	6.20
Husked grain yield	t/ha	2.70	4.65
Straw yield	t/ha	3.15	4.55
Unfilled/damaged grain	kg/t	160.83	77.50
Rice husk	kg/t	362.50	265.00

Discussions on Results

The problems found in irrigated soil, plant growth and yield performance of rice at the polluted site were closely associated with water quality of the Bangshi River. The quality of irrigation water at the polluted site was alkaline and the values of pH were found to be higher than both the irrigation water quality standards (Table 1), which might have affected the content and uptake of nutrients in rice plant by causing nutritional imbalance (Ayers and Westcot, 1994). The evidence of infiltration problem of water in the rice field at the polluted site was identified by measuring the relative content of sodium and calcium, and the values of SAR and EC of irrigation water. The average Na concentration in the river water exceeded Ca concentration by a factor of almost 26 at the PS. Ayers and Westcot (1994) stated that when Na concentration exceeds Ca concentration by a factor of 3, soil dispersion and structural breakdown occurs due to lack of sufficient Ca to counter the dispersing effects of Na. They also mentioned in table of the guidelines for interpretations of water quality for irrigation that infiltration rate of water into the soil is severely affected when the values of SAR and EC fall within the ranges of 20-40 and <2.9 dS/m, respectively. It is found from the results (Table 1) that the average values of SAR and EC in irrigation water at the polluted site fall within the aforementioned ranges, respectively. Therefore, the polluted site was suffering from a severe water infiltration problem and could explain the local problems like poor seedling emergence, occurrence of plant and root disease, algal development (S_3), prevalence of pest (S_5), weeds (S_6) and mosquitoes (S_7), water-logged condition, etc.

According to the guidelines for interpretations of water quality for irrigation (Ayers and Westcot, 1994), saline river water at the PS might have moderately affected the water potential gradient from soil to the plant cell due to the osmotic effect. As a result, rice plants might be in water stressed conditions in terms of lower uptake of water though water was available in the rice fields. It was reported that the measurable or visible effects of salinity on plants can include reduction in growth rate, damage of meristems in growing shoots, reductions in yield components of rice, or typical symptoms of nutritional disorders under osmotic and ionic stress (Shannon et al., 1998; Zeng and Shannon, 2000). Therefore, the toxicity of specific ions (Na and Cl) might have also occurred severely in rice plants as their values in irrigation water were found to be about 562 and 586 ppm, respectively, at the PS. This statement can be strongly validated from Ayers and Westcot (1994) as they reported that Na and Cl ions of more than 207 and 354 ppm, respectively, occur severe toxicity in rice plant. Moreover, the changing leaf colour to red (P_3) exposed in the rice field at the PS also clearly validates the foregoing statement. A toxicity problem due to the ionic stress is different from a salinity problem in that it occurs within the plant itself and is not caused by a water shortage. Toxicity problems occur if certain ions (Na, Cl, etc.) in the soil or water are taken up by the plant and accumulate to concentrations high enough to cause crop damage or yield reduction (Ayers and Westcot, 1994). In addition, the accumulations of excessive Na and Cl ions reduce the stomatal conductance and inhibit the photosynthetic mechanism (Kurban et al., 1999).

The continuous use of saline water coming from upstream industries might have resulted in some exposed soil and plant related problems such as S_4, P_2, P_5, P_6, P_7, P_8, P_{10} and P_{11} (Table 5) in the rice field at the polluted site. Moreover, the aforesaid soil and plant related problems were found to be within 3-90 DAT in the rice field irrigated with polluted water of the Bangshi River. Therefore, the vegetative and reproductive stages were found to be more vulnerable in terms of soil and plant related problems at the polluted site (Asch and Wopereis, 2001; Zeng et al., 2001).

The local farmers of both the study sites always maintained sufficient water in the fields. But continuous ponding with water of higher salinity could have badly affected the growth and yield performances of rice at the polluted site. Zeng et al. (2003) reported that there is a significant negative correlation between the depth of irrigation and the establishment of seedlings and grain yield of rice, where deep ponding of saline water reduces grain yield by inhibiting the formation of productive tillers. It is also presumed that the high salinity in irrigation water coupled with N and P deficiency in soil lowered the uptake of nutrients and finally reduced the growth and yield parameters of rice at the polluted site. This assumption directly matches with the findings of relevant studies conducted in home and abroad (Asch et al., 2000; Zeng et al., 2001; Saleque et al., 2005). According to the database tabulated in Ayers and Westcot (1994), it is evident that salinity level of about 2.6 dS/m in irrigation water alone decreased rice grain yield up to 10% at the PS.

Farmers of Site I informed that the growth of rice plants was high at the vegetative stage but it was low at the subsequent reproductive and ripening stages. Furthermore, most of the rice plants in the same site became weak and fell down on the ground at 55-65 DAT (P_9). Thus, it appears that high concentration of N in the form of ammonium (Table 1) was beneficial during the early growth stage but may have caused detrimental effect on growth and yield of rice at the later stages. Ayers and Westcot (1994) reported that in many grain crops, excessive vegetative growth due to high N contents produces weak stalks which cannot support the grain weight, resulting in severe lodging and difficulties for harvesting.

The continuous irrigation with river water containing higher concentrations of heavy metals increased the accumulation of metals in irrigated soil throughout the growing stages of rice (BRRIdhan-29) at the PS

(Tables 1 and 4). Consequently, the higher concentrations of metals found in irrigation water or irrigated soil or both exacerbated the adverse effects on vegetative growth and yield performance of rice at the same site by decreasing the contents and uptake of essential nutrients, and increasing the accumulation of metals in rice plants and grains. Several studies also reported that higher concentrations of heavy metals in water or soil or both decrease the grain and straw yield, plant height, tiller number, panicle length, grains per panicle, weight of 1000 grains, and contents and uptake of mineral nutrients; and increase the unfilled grains, rice husks and the metal concentrations in plants and grains of rice (Sarkunan et al., 1989; Lidon and Henrique, 1993; Mishra et al., 1997; Shah and Dubey, 1998; Khan, 2001; Shah et al., 2001; Wang et al., 2001; Pammy, 2003; Chatterjee et al., 2004; El-Sharkawi et al., 2004; Sahrawat, 2004; Hassan et al., 2005; Lin and Kao, 2006; Lokeshwari and Chandrappa, 2006; Rahman, 2006; Abbas et al., 2007; Chen et al., 2007).

The foregoing discussions clearly show the reasons for the decline in soil quality, the exposed problems in the rice field and the reduction in growth and yield performances of rice (BRRIdhan-29) at the polluted site. In addition, the yield reduction of rice was found to be about 30% and 42% in unhusked and husked conditions, respectively, at the same site compared to those at the control site. It has been inferred that a sizeable portion of yield reduction of rice at the PS was caused by the continuous use of saline as well as alkaline water of the Bangshi River. The findings of the study partially agree with the results of Pazhanivelan et al. (2006) and Minhas et al. (2007). They reported that continuous use of saline as well as alkaline water resulted in yield reduction of 18-35% and 14-55%, respectively, for paddy in India. The rest of the yield reduction could be due to the higher concentrations of heavy metals in both water and soil, and the excessive concentration of ammonium-nitrogen in water of the Bangshi River at the PS.

Conclusions

The water quality of the Bangshi River at the polluted site was tremendously degraded mostly by untreated industrial effluents, which successively affected the irrigated soil and the growth and yield performances of rice. The cultivators of the downstream part (Site I) in the study area still use the polluted water for irrigation in every subsequent *boro* season as the surface water becomes scarce in terms of both quantity and quality during the dry season, and the cost of irrigation with ground water is high. The present study did not include the experimentation of heavy metal accumulation in rice grain in the study area which might be a good help in understanding the contribution of heavy metals and nutrient uptake in yield performance. In future, this kind of research would be invaluable in assessing and tracing out of the responsible heavy metals for reduction of rice yield and in taking management measures accordingly.

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