EFFECTS OF INDUSTRIAL POLLUTION AND ARSENIC CONTAMINATION ON YIELD AND METAL ACCUMULATION IN RICE GRAIN AND SOIL

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This is to certify that the thesis entitled, "**EFFECTS OF INDUSTRIAL POLLUTION AND ARSENIC CONTAMINATION ON YIELD AND METAL ACCUMULATION IN RICE GRAIN AND SOIL**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in the partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY IN SOIL SCIENCE**, embodies the result of a piece of bona fide research work carried out by *MOST. NASRIN BEGUM,* Registration No. **15-06996** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: June, 2019
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Dedicated
to
My Family

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ABSTRACT

Most. Nasrin Begum

Heavy metal accumulation in rice grain appears to be a perilous problem because of application of chemical fertilizers, irrigation with arsenic (As) contaminated groundwater and use of industrial effluents. The present study was done to assess the yield and metal accumulation in Boro (BRRI dhan 28) and T. Aman (BRRI dhan 33) rice grown in industrially polluted and arsenic (As) contaminated soils. Treatments of the first pot culture experiment were T_0 – Control treatment; T_1 - $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF) and T_2 - $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6 ton cowdung ha^{-1}) in industrially polluted soils (S_1 – Non-polluted soil, S_2 – Polluted soil-1 and S_3 – Polluted soil-2). For the second pot experiment, different levels of irrigation (I_1 – Traditional irrigation and I_2 – Alternate wetting drying) were added along with fertilizes and manure doses (T_0 – Control; T_1 - $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF); and T_2 - $N_{150}P_{60}K_{60}S_{20}Zn_{3.0}$; T_3–($N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF)+ 6 ton cowdung ha^{-1} and T_4 - $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF)+ 5-ton compost/ha) were considered as treatments for As-contaminated soils. Both the pot experiments were carried out in the net-house during December 2015 to November 2016. The experiments were laid out in a 2- factor Randomized Complete Block Design (RCBD) with three replications. Results indicated that heavy metal accumulation and yield reduction were more prominent in both types of contaminated soils compared to non-contaminated (control) soils. In contaminated soils, the minimum yield of Boro and T. Aman rice were observed in T_0S_3 and the maximum yield was in T_2S_1 followed by T_1S_1 treatment. However, the maximum value of Cd, Pb and Zn accumulation in the grains of both Boro and T. Aman rice was found in the T_1S_3 treatment, while the lower values were noted in T_0S_1 treatment. Elevated levels of heavy metals such as Zn, Cd, Pb, Cr and Ni were found in soils receiving T_1S_3 treatment. In case of As contaminated soils, the minimum yield for both Boro and T. Aman rice was obtained in T_0I_2 followed by T_1I_2, and the maximum yield was in T_4I_1 followed by T_3I_1 treatment. Higher accumulation of Cd and Zn in both Boro and T. Aman rice, As in Boro rice, and Pb in T. Aman rice grains were recorded in the treatment T_2I_2, while the lowest values were noted in T_0I_1 treatment. The higher and lower values of the heavy metals were recorded in T_4I_1 and T_0I_2 treatments, respectively. In addition to pot experiments, a field survey was done in Gazipur Sadar upazila to investigate the effect of toxic heavy metals and the contaminated wastewater on the livelihood and food safety of the people living adjacent to industrial areas. The survey results revealed that industrial effluent contamination remarkably affected rice production and further it caused deterioration of grain quality leading to low market price. Nevertheless, industrial effluents are directly or indirectly causing several socioeconomic, health and environment-related problems.

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
ABC	ATP-binding Cassette
ANOVA	Analysis of Variance
ATM	ABC transporters of the mitochondria
BDT	Bangladeshi Taka
BRRI	Bangladesh Rice Research Institute
CDF	Cation Diffusion Facilitator
DEPZ	Dhaka Export Processing Zone
dH2O	Distilled water
DTPA	Diethylenetriaminepentaacetic Acid
DW	Dry Weight
FGD	Focus Group Discussion
FPOX	Ferulic Acid
FYM	Farmyard Manure
GDP	Gross Domestic Product
IE	Industrial Effluent
IREG	Iron-regulated Protein
LMW	Low-molecular-weight
MDA	Malondialdehyde
NIP2;1	Nodulin 26-like Intrinsic Protein
NRAMP	Natural Resistance-associated Macrophage Protein
OM	Organic Matter
PCI	Problem Confrontation Index
POD	Peroxidase activity
PRA	Participatory Rural Appraisal
RCBD	Randomized Complete Block Design
RDCF	Recommended Dose of Chemical Fertilizer
ROS	Reactive Oxygen Species
SAU	Sher-e-Bangla Agricultural University
SEs	Standard Errors
SPSS	Statistical Package for Social Sciences
STW	Shallow Tube Well
TBARS	Thiobarbituric Acid Reactive Substance

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CHAPTER I

INTRODUCTION

Heavy metals-induced contamination in the environment especially in agricultural land has attracted much attention from worldwide environmentalist's, aggravated by natural and anthropogenic activities. The most significant natural sources are weathering of minerals, erosion and volcanic activity while anthropogenic sources include mining, smelting, electroplating, use of pesticides, phosphetic and other fertilizers as well as biosolids in agriculture, sludge dumping, industrial discharge, atmospheric deposition, etc. (Fulekar *et al*., 2009; Sabiha-Javied *et al*., 2009; Wuana and Okieimen, 2011; Islam *et al*., 2014).

The problem of heavy metals' pollution is becoming a severe one with time as a consequence of increasing industrialization and disturbance of natural biogeochemical cycles, resulting in environmental, agricultural and human health problems (Fahad and Bano, 2012; Fahad *et al*., 2015). The most common heavy metals are lead (Pb), cadmium (Cd), nickel (Ni), zinc (Zn), copper (Cu), iron (Fe), chromium (Cr), and manganese (Mn) (Goyer, 1997; Adrees *et al*., 2015; Anjum *et al*., 2016a, b; Shahzad *et al*., 2018; Bakhat *et al*., 2017). Some of these metals such as Mn, Ni, and Zn are considered as indispensable metals for plants although required in small quantities and further play a crucial role in several physiological processes of plants (Goyer, 1997; Kabata-Pendias, 2010). Meanwhile, some other metals like Cd and Pb are dispensable and have no known significant biological role. These metals accumulate in higher concentrations and interrupt in the normal functioning of the plant by causing structural, physiological, and functional alterations (Goyer, 1997; Kabata- Pendias, 2010; Nagajyoti *et al*., 2010; Afshan *et al*., 2015; Shahzad *et al*., 2016, 2017).

Besides the above-mentioned heavy metals, some metalloids like Arsenic (As) have emerged as a potent source of environmental pollution, and their severity augmenting day by day due to extensive use of As contaminated ground water from shallow tube wells to irrigate the paddy fields (Kalita et al., 2018). As a result, in rice grains As content has been found to rise at alarming levels, that eventually, brings a threat to food safety and crop production in near future (Rahman and Hasegawa, 2011). In the last decade, emergence of different industries has noticed in Bangladesh, specifically the textile and composite industries, which producing huge amounts of effluents (Saha, 2007). The Gazipur district is one of the major industrial areas of Bangladesh having a number of industries, where effluents are directly discharged to the environment without treatment. Although every industry has an effluent treatment plant as per the rules of government, regardless the plants are not generally operated because of the high cost involved in treating effluents.

The sustainable use of environmental resources is in great concern due to the release of untreated effluents to the environment (Eruola *et al*., 2011). Untreated industrial effluent degrades surface water and soil, and ultimately causes negative impacts on crops, insect pests, animal and human lives (Hossain *et al*., 2010). Substantial variation is observed in the toxicity of industrial effluent among different industries (Rautaray *et al*., 2007). Considering both the volume and composition of effluents, the textile effluent is the most potent polluting among all industrial sectors, in both developed and developing countries (Vanndevivera *et al*., 1998; Roy *et al*., 2010). Moreover, in textile and composite industries consumption of water is very high (Roy *et al*., 2010). The effluents are contaminated with different chemicals and toxic components and harboring a number of detrimental pathogens that are the causal agent of many diseases of humans and other living organisms (Molla *et al*., 2004). In soils, heavy metal concentration was found to vary depending on the types of effluents and decreased with distance from the discharge area because of the dilution effect of effluent by water (Nuruzzaman *et al*., 1993). Heavy metals can exaggerate their toxic effects even at low concentrations and cannot be degraded with time and their concentrations may be increased through bioaccumulation (Aksoy, 2008; Clark, 1992; Davey *et al*., 1973; Hussain *et al*., 2008).

Rice (*Oryza sativa*) is an agro-economically important cereal crop, which is consumed as the chief source of carbohydrate by almost half of the global population (more than 3 billion) (Ghosh *et al*., 2016). In Bangladesh, rice is the most important cereal crop, contributing roughly 77% of calories and 65% of protein intake for the population (Hossain *et al*., 2015; Mottaleb and Mishra, 2016). Rice can be grown all over Bangladesh almost throughout the year. Out of 315 cropping patterns, the most important five patterns covering more than 50% of the cultivable land and are belonging to rice-based cropping patterns (Biswas *et al*., 2019). Nevertheless, the contribution of rice in the gross domestic product (GDP) is decreased presently and stands at 7% (Biswas *et al*., 2019). It is worth mentioning that there is a substantial yield gap between research and farmers yield as the arable land is prone to many biotic and abiotic stresses. Furthermore, the per capita arable land in Bangladesh is only 0.04821 ha, which is experiencing a decreasing trend at the rate of 0.7% due to the obtrusive growth of population and the extended use of land for nonagricultural purposes (Biswas *et al*., 2019). Most importantly, the present population of Bangladesh is approximately 162.7 million and it is anticipated that the country will have a huge number of populations of 202 million by the year 2050 (BBS, 2018; UN, 2015). Therefore, it exerts an additional challenge to produce a supplementary amount of rice to feed the extra millions of people in the upcoming years to achieve sustainable food security (Kabir *et al*., 2015).

Due to shrinking of arable land, people already started to cultivate rice in industrial prone area, which are being continuously flooded with industrial wastewater. However, production of rice in industrial areas of Bangladesh is a big question and there are limited reports on the impact of industrial effluents as irrigation water on rice. Predominantly, soils contain excess heavy metals restrains the growth and grain yields of rice by perturbations of different morpho-physiological and biochemical attributes resulting from the translocation of heavy metals from soils to root and root to above-ground plant parts (Du *et al*., 2013; Liu *et al*. 2016; Fahad *et al*., 2019; Pandey and Dubey 2019). To ameliorate the metal toxicity in rice, various strategies including simple and less expensive technologies should be developed for low-income countries like Bangladesh. In this context, exploration of the potential roles of organic amendments and judicial application of fertilizers may provide an effective solution for the improvement of plant resiliency toward the adverse effects of ever-changing environmental hazards. In soils, implementation of organic amendments like farmyard manure (FYM), compost, bio-solids or bio-solid compost may efficaciously reduce the bioavailability of heavy metals due to their high content of organic matter and high concentrations of phosphorus (P) and iron (Fe) (Puschenreiter *et al.*, 2005). With this clue, it has been anticipated that this cost-effective and easily accessible organic amendments in addition to a reduced portion of recommend doses of inorganic fertilizers might have influential roles in the management of metal-induced adverse effects in rice.

Nevertheless, prior to any intensive research, it is important to collect the relevant field level information by face-to-face interview or field survey. A survey in the present study is anticipated to help to get an overview of how and what extent of crop yields being affected by different industrial effluent. Furthermore, differences between pre-and post-industrial exploration-induced environmental deterioration in terms of air, water and soil quality is also assume to be clear through field survey. Considering the above-mentioned scenarios, and to generate information about the impact of toxic metals in wastewater on the livelihood and food security of the local people around the industrial areas of Gazipur district a research study was conducted with the following objectives.

The objectives of the research were to-

- Assess the metal accumulation in rice and soils of industrially polluted areas
- Evaluate the rice arsenic accumulation in arsenic contaminated soils as influenced by irrigation and fertilizer management,
- Determine the quality of grain as influenced due to application of industrial wastewater irrigation,
- Investigate the industrial pollution impacts on the socioeconomic condition of the farming community.

CHAPTER II

REVIEW OF LITERATURE

2.1 Rice production scenario in the world and in Bangladesh

The present world population of 7.6 billion is increasing at an alarming rate and expected to reach 8.6 billion by 2030, 9.8 billion by 2050, and 11.2 billion by 2100 (UN, 2017). The increasing fuel prices, depletion of underground water, habitat loss, urbanization, frequent floods and droughts due to climate change are major obstacles to achieving the projected increase of world food production. In 2016, a total of 108 million people across the world faced food insecurity, which resulted largely from drought conditions that damaged agricultural livelihoods (FAO, 2017).

Rice, the staple food for the majority of the Asia’s 4.5 billion people is grown on about 144 million hectares producing about 640 million metric tons of paddy rice. More than 90% of rice is produced and consumed in Asia. More than four billion of world’s population eats rice every day. Rice grain constitutes 20% of the world’s dietary energy supply, which is more than other cereals such as wheat (19%) and maize (5%). Rice production and consumption is critical to sustain global food security. Countries such as Cambodia, Myanmar, and Bangladesh depend on rice for over 70% of their energy supply (FAO, 2017). Globally, Asia is a net exporter of rice accounting for 70% of global rice exports. The traded volume of rice accounts for only about 7% of total world consumption, which is minute. As both the world’s main supplier and consumer of rice, what Asia does for its food security will have considerable effects on global food security. Although global rice production has more than tripled between 1961 and 2010, with a compound growth rate of 2.21% per year in Asia but the success of the Green Revolution in the 1960s witnessed a rise in per capita rice consumption from 85 to 100 kg between 1960 and 2010 (Abdullah *et al.*, 2008). In Asia, rice consumption is projected to increase from 388 million metric tons in 2010 to 465 million metric tons in 2035 (Maclean *et al.*, 2013, http://ricepedia.org). Presently the yield of rice varieties is on an average of 4.5 t ha^{-1} under irrigated conditions. There needs to be at least 8-10 million metric tons more rice cultivation each year with an annual increase of 1.2-1.5% (0.6 t ha^{-1}) over the coming decade, as the pressure on rice growing lands is increasing globally day by day because of climate change, urbanization, and competition from other, high-value agriculture in the developing world. Sustainable production of rice is the main livelihood of around 140 million rice-farming households and for millions of poor rice farming-based laborers. Globally, the sufficient, affordable, and constant supply of rice strengthens economic growth and political stability.

The on-going climatic changes threaten world food security and are currently the most important obstacles in the way of increasing crop production and feeding the increasing populations of the world. The population density of Bangladesh in 2016 was 1252 people's km^{-2}, the highest in the world while having a per capita arable land of only 0.04821 ha, which is also experiencing a decreasing trend at the rate of 0.7% due to population growth and the increased use of land for nonagricultural purposes (housing, trading, economics and commerce). Rice is the staple food for 165 million people in Bangladesh and is the major source of calorie (77%) and protein (65%), and per head consumption is at least 432 g of rice per day (Mottaleb and Mishra, 2016). The contribution of rice in the gross domestic product (GDP) is also decreasing (at present it stands at 7%). However, the socio-political importance of this staple food crop is more important than that of its economic importance. Rice can be grown all over Bangladesh almost throughout the year. Out of 315 cropping patterns, the most important five patterns covering more than 50% of the cultivable land belong to rice-based cropping patterns (Nasim *et al*., 2017). Still, there is a substantial yield gap between research and farmers' yield (Mainuddin and Kirby, 2015).

Fortunately, the country has earned self-sufficiency in rice production and even has started exporting (BER, 2015). Bangladesh will, however, need more rice to feed the increasing population, which is currently growing at 1.1% per year. A model-estimate, as presented by Kabir *et al*. (2015), showed that the population will reach to 170.8, 187.6, 203.0, and 215.4 million in 2021, 2031, 2041, and 2050, respectively. This will significantly affect the volume of rice required. Taking 2014 as the baseline, the demand for rice in Bangladesh in 2021, 2031, 2041, and 2050 will go up by 1%, 11%, 20%, and 27%, respectively. It remains an important challenge to ensure sustainable increases in rice production in the future, to guarantee a sufficient, reasonable, and stable supply of rice to poor consumers. Future rice farming is facing several challenges, such as the need to produce more rice in order to meet the rising demand of the increasing population coupled with environmental degradation associated with intensive cultivation practices, increasing competition for water, labor, land, and energy, global climate change, urbanization, and industrialization. Moreover, heavy metal-induced contamination in the environment, especially in paddy field of agricultural land has recently been emerged as an incipient problem due to its high persistence, non-degradability and toxicity nature (Song *et al*., 2014; Yu *et al*., 2016).

2.2 Heavy metals in agro-ecosystem

From plant health point of view, heavy metals are divided into two categories. Some metals are required by plants as essential micronutrients for proper plant growth such as Zn, Cu, Fe, Mn and Ni at very low concentration (Fageria *et al*., 2009). But excessive levels of these metals are toxic to plants and can cause growth inhibition, soil quality deterioration, yield reduction and poor quality of food with a potential health risk to human and animals (Seth *et al*., 2007; Seth, 2012). While some metals and metalloids are essentially heavy metals with no known biological functions in plants such as arsenic (As), chromium (Cr), silver (Ag), cadmium (Cd), lead (Pb), selenium (Se) and mercury (Hg) (Seth, 2012). However, heavy metal enters agro-ecosystem through both natural as well as anthropogenic sources.

Natural sources: The most important and primary source of heavy metals is the parent material from which a soil has been originated. Of the total earth crust, 95% is made up of ingenious rocks and about 5% sedimentary rocks (Thornton, 1981). Among the former, basaltic ingenious rocks contains heavy metals like cobalt (Co), cadmium (Cd), zinc (Zn), cupper (Cu) and nickel (Ni) generally in higher concentrations while among the latter, shales derived from fine sediments of organic and inorganic origin have larger amounts of metal elements i.e. Zn, Cu, Mn, Cd and Pb. Generally, these heavy metals exist in most of the soils as carbonates, sulfides, oxides or salts. The dominant mineral of every metal may vary from soil to soil.

Anthropogenic sources: Recent advancements in industry and agriculture sector contributed a lot in elevated heavy metal contamination in soils and water resources. Mining and smelting activities are important point sources of heavy metals in agro-ecosystem. Use of metal containing substances and contaminated biosolids and fertilizers also play their role in this scenario (He *et al*., 2005; Sarwar *et al*., 2010; Czarnecki and Düring, 2015). For sustainable crop production, some metals especially Zn with other phosphatic fertilizers must be applied in soil (Imran *et al*., 2016a) or foliar spray on plant leaves as essential micronutrient (Rehim *et al*., 2014; Imran *et al*., 2015; Imran and Rehim, 2016). For insect pest and disease management, different chemicals like insecticides, fungicides, and herbicides have to be applied on large scale, also an important source of some elements like Cu, As, Zn and Fe etc. (Fageria *et al.*, 2002).

Fertilizer especially phosphorous (P) fertilizers such as triple super-phosphate and calcium phosphate contain heavy metals (mostly Zn and Cd) in varying concentrations depending on rock phosphate source. Some rock phosphate sources have Cd concentration even more than 50 mg kg^{-1} of soil and are banned in many countries for agricultural use (Mortvedt and Beaton, 1995). Likewise, Zn, Fe, Cu, Mn and boron (B) containing compounds are also being used for proper plant growth and yields. Czarnecki and Düring (2015) found that long-term use of mineral fertilizer increased the soil metal content, however, eight years' termination of the fertilization reduced the soil Cd, Cu, Mn, Pb, and Zn contents by 82.6, 54.2, 48.5, 74.4, and 56.9%, respectively. Other than fertilizers, some organic compounds such as farmyard manures, composts and bio-solids containing higher concentrations of heavy metals than in most of agricultural soils are also applied to soils for improving soil fertility status or reclamation of problem soils.

The extent of contamination of soils with heavy metals through irrigation varies from location to location depending upon the level of contamination in irrigation water. Fresh water non-contaminated sources contribute extremely very low level of contamination, while application of sewage and industrial wastewaters often contain high concentrations of heavy metals. Repeated use of untreated wastewaters for irrigation purpose may be a considerable input source of some metals. Dry and wet deposits of emissions from different point sources including steel industry, metal smelters, metal refineries, foundries and cement industries have also a great contribution to metal accumulation in soils (Freedman and Hutchinson, 1981). Moreover, emissions from automobiles using lead enriched fuel are responsible for significant Pb accumulation in soils near highways. Mining activities have also been reported to contaminate the soils with heavy metals in localized areas (Webber, 1981).

2.3 Metal uptake, translocation and accumulation within the plants

Mobilization of metals, their uptake from soil by the plant roots, compartmentation and sequestration, xylem loading, distribution in aerial parts, and storage in various tissues are the key events associated with the accumulation of metals within plants. The process of metal uptake is influenced by the complex nature of the rhizosphere, the soil solution composing it, and the microorganisms present within the rhizosphere (Tak *et al*., 2013). Among rice varieties, the accumulation of metals in the shoots and grains are potentially higher in *indica* cultivars than in the *japonica* cultivars and some specific *indica* rice cultivars have been shown to accumulate very high levels of Cd in their vegetative tissues and grains (Uraguchi *et al*., 2009).

In soil metals primarily exist in insoluble bound forms and need to be mobilized into the solution so that they are made available to the plants. A number of biotic as well as abiotic factors such as temperature, soil pH, soil aeration, Eh conditions (particularly of aquatic environment) and fertilization, competition between the plant species, types of plants and its size, the root system, availability of the elements in the soil or foliar deposits, soil moisture, and plant energy supply to the roots and leaves influence metal uptake rates in plants (Nagajyoti *et al*., 2010). Many plant species employ certain strategies to facilitate the bioavailability of metal ions like the secretion of phytosiderophores, carboxylates, and acidification of the rhizosphere for better chelation and solubilization of soil bound metals (Thakur *et al*., 2016).

Metals available in the soil environment are taken up by plant roots via two pathways, either through inter cellular spaces (apoplastic pathway) or by crossing plasma membranes (symplastic pathway) depending on the type of metal species (Hossain *et al*., 2012). Most metal ions are taken up by plants through a highly effective, energy dependent, active process involving specific metal- ion carriers, transporters, or channels (Zhu *et al*., 2011). Availability of many metal ions in the soil for their uptake by plants is increased due to the acidification of rhizosphere by exuding low-molecular-weight (LMW) compounds that act as metal chelators. The carrier molecules associated with uptake can be complexing agents, such as organic acids or proteins that bind to the metal ions. A number of metal transporters have been identified that have specific roles in metal uptake and translocation within plants. Sometimes, different valence species of the same metal may have different uptake processes. In rice roots (*Oryza sativa*), arsenate uptake is mediated via a phosphate transport process, whereas, arsenite uptake is mediated by aquaporin NIP2;1 (Nodulin 26-like Intrinsic Protein), which is a highly efficient silicon (Si) transporter (Bakhat *et al*., 2017).

The entry of metals from the root into the xylem is determined by processes such as metal-ion sequestration into root cells, symplasmic transport into the stele, and release into the xylem (Saxena and Misra, 2010). Transport of metal ions from root to shoot through xylem is accompanied by complexation with chelators, such as organic acids, amino acids (citrate and histidine), methionine-derivative nicotinamine (NA), etc. (DalCorso *et al*., 2013). A number of transporter proteins are also involved in the transport of metals. Well-known proteins that mediate the transport of metals in plants are ATP-binding cassette (ABC) transporters, the P_{1B}-type subfamily of P-type ATPases, the natural resistance-associated macrophage protein (NRAMP) family, multidrug resistance-associated proteins, zinc-regulated transporter and iron-regulated transporter proteins (ZIP family), ABC transporters of the mitochondria (ATM), cation diffusion facilitator (CDF) family of proteins, copper transporter family of proteins, pleiotropic drug resistance transporters, Ca^{2+} sensitive cross complementer 1 family of proteins, iron-regulated protein (IREG) family, yellow- stripe 1-like subfamily of the oligopeptide transporter superfamily, etc. (Singh *et al*., 2016). Arsenate enters the rice roots as a phosphate analogue (PO_4^{3-} transporters) and then it gets reduced to arsenite. This uptake is inhibited by phosphate, suggesting that phosphate and arsenate are taken up by the same uptake system. A number of aquaporins are able to transport arsenite, the predominant form of arsenic present in the reducing environment (Bakhat *et al*., 2017).

Transportation of metals and its distribution in leaves and different organs occurs via apoplast or symplast (Mahmood, 2010). Moreover, the trichomes appear to play an important role in storage and detoxification of metals.

2.4 Effects of metal/metalloids toxicity on rice growth

Effects on germination and seedling growth stage: Germination of seed is a fundamental and vital phase to initiate plants life in the beautiful earth, which severely impeded by the metal-induced toxicity. Lead adversely affects seed germination, root/shoot ratio, and fresh and dry weight in rice (Sethy and Ghosh, 2013). The effects were more adverse at higher concentrations of Pb^{2+}. Cadmium stress accumulated high thiobarbituric acid reactive substance (TBARS) and Cd content in the seeds. However, a decrease in seed germination, shoot growth, water content, and biomass was observed under Cd stress. Twenty-one proteins were upregulated under Cd stress, which are involved in different processes like antioxidant activation, detoxification, germination, and protein biosynthesis (Ahsan *et al*., 2007a, b). He *et al*. (2008) studied the effect of Cd on rice seed germination and growth. They observed that Cd stress restricted seed germination and radicle and plumule growth. Furthermore, rice cultivar Xiushui 11 had lower germination/vigor index, radicle growth, and α -amylase activity compared to Xiushui 110 due to higher Cd accumulation, which lowered mitotic index in the tips of rice roots. Copper stress reduced seed germination, shoot growth, water content, and plant biomass with increased TBARS and Cu accumulation in seeds. Protein profiling using 2-DE showed that 25 different proteins were expressed in Cu treated plant samples with down- and upregulation of 7 and 18 proteins respectively. Genes of stress related proteins and some up-regulated antioxidants like, aldose reductase, peroxiredoxin, glyoxalase I, UlpI protease, DnaK-type molecular chaperone, and receptor-like kinase showed that Cu excess causes oxidative stress which disturbs other metabolic processes. However, germination inhibition and failure to mobilize food reserves is due to downregulation of α -amylase and enolase (Ahsan *et al*., 2007a, b). If Zn contamination is high in soil, rice seedlings will die after 10 days of germination (Silva *et al*., 2014).

Effects on rice vegetative stage: Symptoms of heavy metal toxicity appear first on young leaves with the formation of dark green ribs. Under severe toxicity, the leaves become chlorotic and ultimately turn white. Heavy metal toxicity interrupts the physiological and biochemical traits of rice. For instance, Chatterjee *et al*. (2004) found that Pb toxicity lowered the chlorophyll, carotenes, nitrogen, and protein contents. However, certain enzyme activities such as, acid phosphatases, ribonucleases, and catalases were enhanced under Pb stress. High accumulation of Pb reduced the growth and photosynthetic pigments with ultrastructural alterations in the pollens of the two rice cultivars. Lead toxicity adversely affected photosynthesis by disintegration of chloroplast structure, biosynthesis of photosynthetic pigments, reduced CO_2 fixation and enzyme activity of the carbon metabolism, and disrupted

ETC (Xiong *et al*., 2006; Singh *et al*., 2010). It also alters the thylakoid membrane lipid composition (Stefanov *et al*., 1995). Lower chlorophyll biosynthesis due to Pb stress is owing to limited Fe and Mg uptake (Burzynski, 1987). Nickel reduced the root growth of rice seedlings and was pH dependent, however, it also caused an increase in ferulic acid (FPOX) and syringaldazine peroxidase activity and lignin content was observed with $NiSO_4$ application (Lin and Kao, 2005). Cadmium stress results in reduced thylakoid, photosynthetic pigments, O_2 evolution, and Fv/Fm in leaves. However, the structure of the photosystem remained intact. Cadmium affects water splitting by loss of thylakoid ability to a 2,6-dichlorophenolindo-phenol reduction. Diphenylcarbazide preserves PSII activity lost due to Cd stress (Pagliano *et al*., 2006). It was further noticed that Cd accumulation was higher in roots followed by stem and grain. Moreover, Cd toxicity enhanced MDA contents due to higher lipid peroxidation. Peroxidase activity (POD) was also inhibited at 5.00 mg L^{-1} Cd stress (Xie *et al*., 2015). Grain yield reduced by Cd (9 mg kg^{-1}) and Pb (50 mg kg kg^{-1}) application by 28% and 34%, respectively. Similarly, Cd application declined the shoot (35%) and root weight (24%). Moreover, Pb application reduced the shoot (54%) and root biomass (43%). Moreover, Cd and Pb accumulation was higher in sandy loam, sandy clay loam and clay loam soil (Kibria *et al*., 2006). Heavy metal application (Cd and Zn) reduced the root growth by lowering length, surface area, diameter, and activity of rice roots. The root cortical cells were severely damaged under heavy metal stress as observed from transmission electron microscopy. Moreover, Cd and Zn stress also lowered the tartaric, maleic, acetic, oxalic, and fumaric acid concentrations in the root exudates (Fan *et al*., 2016). Heavy metal (Cd/Cu) accumulation reduced the plant biomass, root morphology through higher lipid peroxidation, lipid saturation and modulation in salicylic acid, abscisic acid, and jasmonic acid in response to heavy metal stress (Kim *et al*., 2014). Copper (Cu) stress inhibited the root growth of rice seedlings with escalated lipid peroxidation. In another study, the accumulation of high concentrations of Ni^{2+} in rice caused chlorosis and necrosis was observed by Samantaray *et al*. (1997). Rice grown in solution cultures with higher Ni concentrations have impaired membrane with disturbed nutrient homeostasis as Ni toxicity affects the H-ATPase activity of the plasma membrane by disturbing the lipid composition (Ros *et al*., 1992).

Overall, reactive oxygen species (ROS) production is the first response to heavy metal toxicity in rice. These ROS are produced through Haber-Weiss reactions directly and over production of ROS results in oxidative stress (Wojtaszek, 1997; Mitho¨fer *et al*., 2004; Shahzad *et al*., 2018; Fahad *et al*., 2016 a, b, c, d). However, the secondary sequence of heavy metal stress is a disturbance in nutrient homeostasis (Dong *et al*., 2006), the electron transport chain, and the antioxidant system (Srivastava *et al*., 2004; Anjum *et al*., 2016a, b). Furthermore, heavy metal toxicity causes lipid peroxidation and bio-membrane disintegration (Demiral and Tu¨rkan, 2005). In rice seedlings, Cd toxicity escalated the oxidative stress due to increased ROS production, MDA contents, and electrolyte leakage (Srivastava *et al*., 2014; Yu *et al*., 2013). Further, it causes ultrastructure alterations in leaves and roots and disintegrates the photosynthetic machinery (Aina *et al*., 2007). Cadmium stress causes oxidative stress by enhancing ROS production, MDA content, and electrolyte leakage (Srivastava *et al*., 2004, 2014; Yu *et al*., 2013). Further, Cd stress up-/downregulated 36 proteins in rice (Lee *et al*., 2013). Zinc toxicity causes condensation of chromatin material with disruption and dilation of the nuclear membranes of some cortical cells. Zn toxicity further causes disintegration of cell organelles, vacuole, and cytoplasm. Zinc toxicity also increases the number of nucleoli leading to de novo protein synthesis for heavy metal tolerance (Rout and Das, 2009). Excess Cu accumulation causes lipid peroxidation, growth inhibition, and modulation of antioxidant activity. However, stimulation of the antioxidant defense system and proline accumulation appears to be effective against Cu induced toxicity (Li *et al*., 2003).

2.5 Heavy metals and metalloids pollution in Bangladesh soils

According to USEPA (2002), the standards for As, Pb, Cd and Cr in the soils are 0.11, 200, 0.48 and 11 mg kg^{-1}, respectively. However, the department of environment in Bangladesh reported that the standards for industrial wastes i.e. industrial waste-mediated irrigated land for As, Pb, Cd and Cr are 0.20, 0.10, 0.05 and 1.00 mg L^{-1}. However, soils near the Hazaribagh leather industrial area of Dhaka being reported to have As, Pb, Cd and Cr at the rate of 1.94, 50.32, 0.45, 976 mg kg^{-1}, respectively (Mottalib *et al*., 2016). Another study at high traffic area of Dhaka reported that soils contained Pb, Cd and Cr 45.68, 0.38 and 31.75 mg kg^{-1}, respectively, which clearly conferred that the Cr level in the soils beyond the permissible limit (Zakir *et al*., 2014). Rahman *et al*. (2012) investigated the metal levels in soils at two consecutive season (dry and wet) in farm land near the industrial area of Dhaka Export Processing Zone (DEPZ), and found that As, Pb, Cd and Cr levels in dry season was 4073.1, 27.6, 0.0072 and 49.66 mg kg^{-1}, respectively, whereas, in wet season it was 2326.2, 9.61, 1.04 and 34.2 mg kg^{-1}, respectively. Zakir *et al*. (2015) reported that the soils collected from high industrial and traffic areas of Gazipur city having Pb, Cd and Cr at the rate of 27.95, 0.41, 29.21 mg kg^{-1}, respectively. Soils collected from the urban and industrial area of Bogra city being reported to contained Pb, Cd and Cr at the rate of 9.61, 6.95, 4.05 mg kg^{-1}, respectively (Begum *et al*. 2014). However, soils of industrial and high traffic areas of Chittagong being reported to possessed 7.33 and 2.43 mg kg^{-}

^{1} of Pb and Cd, respectively (Alamgir *et al*., 2015). In another study, soils collected from the surrounding-cement, -textile and -medicine industry of Barisal district being reported to contaminated with As (2.13, 1.41 and 1.67 mg kg^{-1}, respectively), Pb (23.39, 18.48 and 11.42 mg kg^{-1}, respectively), Cd (0.62, 1.90 and 0.78 mg kg^{-1}, respectively) and Cr (38.26, 132.5 and 25.73 mg kg^{-1}, respectively) (Begum and Hug, 2016). Rahman *et al*. (2015) reported that soils collected from the bank of Brahmaputra river have 26.7, 0.48 and 34.7 mg kg^{-1} of Pb, Cd and Cr, respectively. In another study performed in the industrial area of Tangail district showed that collected soils possessed 6.11, 17.46, 2.01 and 11.56 mg kg^{-1} of As, Pb, Cd and Cr, respectively (Proshad *et al*., 2018). Soils collected from the mine affected paddy and farmland of Dinajpur (Barapukuria) being reported to contaminated with As (22.44 and 17.55 mg kg^{-1}, respectively) and Pb (435 and 21.29 mg kg^{-1}, respectively) (Halim *et al*., 2015; Bhuiyan *et al*., 2010). In an comparative study with As-laden groundwater irrigated soils of three districts (Noakhali, Naraynganj and Faridpur) 10 regions Khan *et al*. (2010) reported a wide range of As concentration; ranging from (4.0-137.9 mg kg^{-1}), while the only area of Noakhali had less than 10 mg kg^{-1} of As and one area of each Narayngonj and Faridpur districts had severely high level of As (>100 mg As kg^{-1}). Jahiruddin *et al*. (2000) investigated that the soils of Gangetic alluvium contain more As than that of Brahmaputra alluvium and the former soils had more than 20 mg kg^{-1}As, whereas the later soils had As level below 20 mg kg^{-1}, which was below maximum acceptable limit for agricultural soils. They also found that the mean concentration (mg kg^{-1}) in calcareous soil were Pb (22.80), Cd (0.25), Sb (0.74), Mo (0.31), Mn (457), Cu (29.20) and Zn (78.50), whereas in non-calcareous soils were Pb (24. 1), Cd (0.15), Sb (0.31), Mo (0.31), Mn (444), Cu (22.4) and Zn (66.4). Rakib *et al*. (2014) carried out an experiment to assess the heavy metals in Dhaka Metropolitan city. They found that, the highest content of Pb, Zn, Cr and Cu were found in Hazaribagh and the lowest concentration of Pb, Zn, Cr and Cu was observed in Savar Bazar area in the greater Dhaka City. In addition, the minimum concentration of Pb, Zn, Cr and Cu was found to be 30.02 ppm, 49.91 ppm, 61.24 ppm and 12.21 ppm, respectively. Consecutively, the maximum concentration of Pb, Zn, Cr and Cu was identified 198.16 ppm, 283.21 ppm, 303.89 ppm and 179.80 ppm, respectively. However, the average concentration of Pb, Zn, Cr and Cu was observed 67.60 ppm, 144.20 ppm, 124.70 ppm and 98.90 ppm, respectively.

2.6 Heavy metals and metalloids pollution in crops

As a tropical country, Bangladesh produces more than 90 kinds of vegetables and 60 kinds of fruits (Alam *et al*., 2003). Environmental pollution and nature of the soil directly affect the heavy metal and metalloid content in foods. Chemical pesticides and fertilizers containing heavy metals and metalloids are both major sources of heavy metals and metalloids in foods. Some trace metals are essential in plant nutrition; however, excess heavy metals and metalloids can accumulate in various edible and non-edible parts of plants (Mingorance *et al*., 2007). Basically, leafy vegetables are more liable to heavy metal and metalloid contamination, due to their rapid growth and direct transfer of metals and metalloids to the leafy parts (Chang *et al*., 2014). Irrigation with As-contaminated ground water is the primary cause of food As contamination in Bangladesh. Organic As in foods is considered to be less harmful. However, As-contaminated crops may contain a large portion of inorganic As (Meharg *et al*., 2009; Rahman and Hasegawa, 2011). Besides drinking water, food As exposure was also found to an be important pathway responsible for As poisoning (Al Rmalli *et al*., 2005; Khan *et al*., 2010). Alam *et al*. (2003) found that vegetables grown in the Samta village were contaminated by As. Rice from Brahmanbaria also was observed to contain As (0.24 mg/kg) and Cd (0.331 mg/kg) in higher concentrations than the established safe limits (Khan *et al*., 2010). Safe limits for main metals and metalloids in food stuffs are as follows: As 0.1 mg/kg; Pb 0.05 mg/kg; Cd 0.05 mg/kg; and Cr 2.3 mg/kg (FAO/WHO, 2011).

Various studies showed that plants grown nearby industrial areas retain more heavy metals and metalloids than those from non-industrial areas. Eggplant (*Solanum melongena*), chilli (*Capsicum annuum*), tomato (*Solanum lycopersicum*), okra (*Abelmoschus esculentus*) and cabbage (*Brassica oleracea*) collected from nearby of DEPZ being reported to contained Pb (11.97, 13.81, 14.15, 15.72, 22.09 mg kg^{-1}, respectively), Cd (2.91, 2.18, 2.39, 2.81 and 2.05 mg kg^{-1}, respectively) and Cr (6.27, 3.70, 9.03, 6.64, 7.58 mg kg^{-1}, respectively) (Ahmad and Goni, 2010). Edible parts of Spinach (*Spinacia oleracea*) from the Hazaribagh leather industrial area of Dhaka presented higher levels of As (0.26 ± 0.22 mg/kg), Pb (11.48 ± 4.98 mg/kg), Cd (0.32 ± 0.094 mg/kg), and Cr (44.48 ± 12.59 mg/kg) (Mottalib *et al*., 2016). Bottle gourd (*Lagenaria siceraria*) (Pb 1.16 ± 0.01 mg/kg) and water spinach (*Ipomoea aquatica*) Cr (3.21 ± 0.023 mg/kg) from the Vatiary industrial area of Chittagong both exceeded the safe limits (Parvin *et al*., 2014). Potato (*Solanum tuberosum*) from Bogra was found to be polluted by Pb and Cd (Islam *et al*., 2016). Vegetables grown in high traffic areas were also found to contain higher concentrations of heavy metals and metalloids. Naser *et al*. (2012) found that pumpkin (*Cucurbita maxima*) grown close to the highway in Joydevpur, Gazipur, contained Pb (4.76 ± 1.03 mg/kg) and Cd (0.20 ± 0.02 mg/kg) in concentrations much higher than those grown in distant areas.

Irrigation with contaminated river water may substantially affect the metal and metalloid concentrations of vegetables. Red amaranth (*Amaranthus cruentus*) collected from agricultural land surrounding the Turag River were considerably polluted by Pb (1.99 ± 0.44 mg/kg) and Cd (0.84 ±0.17 mg/kg) (Islam *et al*., 2014). Purple amaranth (*Amaranthus lividus*) from agricultural land surrounding the Shitalakhya river was polluted by Pb and Cd as well (Ratul *et al*., 2018). Market samples provide important insights into the average contamination levels of heavy metals and metalloids in foods in Bangladesh. Rice and vegetables from Kawran Bazar, Dhaka, were all found to contain Cd and Pb in higher concentrations than the safe limits (Mih *et al*., 2017). In their market-based study, Shaheen *et al*. (2016) showed that tomatoes (*Solanum lycopersicum*) contained excess Cd. Khan (2016) found that the concentrations of Pb, Cd, Ni, Co, Cr and Mn in different vegetables varied widely. Concentrations of heavy metals were higher in leafy vegetables compared to fruit vegetables, root and tuber vegetables. The highest concentrations of Cd (1.21µg g^{-1}), Ni (8.19µg g^{-1}) were found in spinach while the highest concentrations of Pb (1.37µg g^{-1}) in Amaranth, Cr (17.61µg g^{-1}) in Cauliflower and Co (3.27µg g^{-1}) recorded in Red amaranth and Mn (17.10 µg g^{-1}) in Cabbage. According to his study among all the heavy metals; the Cr concentration was highest in vegetables. In a survey-based experiment Meharg *et al*. (2013) reported that among 260 rice samples collected from 12 of Bangladesh’s 64 districts, most of the samples had Cd concentration above 0.1 mg kg^{-1} and as the cause of this concentration they suggested the efficiency of Bangladeshi cultivars at assimilating Cd, possibly due to genetic variance, edaphic factors, or management practice.

Hoque (2003) conducted an experiment to determine the status of As and other heavy metals and vegetables of five intensively growing areas of Chapainawabganj. He reported that the mean concentration of heavy metal is higher in the leafy vegetables compared to tuber, roots and fruit vegetables. To address the As concentration in rice, vegetables, pulses, and spices, an inclusive food market-basket survey was conducted by Williams *et al*. (2006), where they analyzed 330 *aman* and *boro* rice, 94 vegetables, and 50 pulse and spice samples. They reported that the districts with the highest mean arsenic rice grain levels were all from southwestern Bangladesh: Faridpur (*boro*) 0.51 > Satkhira (*boro*) 0.38 > Satkhira (*aman*) 0.36 > Chuadanga (*boro*) 0.32 > Meherpur (*boro*) 0.29 µg As g^{-1}. Moreover, there was wide variation in As levels between and within vegetable types. Based on maximum recorded As levels the 10 vegetables with the highest As values were arum stolon (1.93 µg g^{-1} DW; dry weight) > brinjal (1.59 µg g^{-1} DW) > cucumber (1.17 µg g^{-1} DW) > lady's finger (1.06 µg g^{-1} DW) > coriander (0.98 µg g^{-1} DW) > potato (0.89 µg g^{-1} DW) > long yard bean (0.87 µg g^{-1} DW) > radish leaf (0.79 µg g^{-1} DW) > giant taro (0.69 µg g^{-1} DW) > vegetable papaya (0.69 µg g^{-1} DW). Nevertheless, the average As levels in pulses did not exceed 0.10 µg As g^{-1} DW, while average total As concentrations in different types of spices varied widely ranging between 0.04 µg g^{-1} in garlic to 0.49 µg g^{-1} in coriander (Williams *et al*., 2006). From there collected 100 samples of rice and vegetables Das *et al*. (2004) observed that rice plants, especially the roots had a significantly higher concentration of As (2.4 mg/kg) compared to stem (0.73 mg/kg) and rice grains (0.14 mg/kg). In response to vegetables, As contents was varied; those exceeding the food safety limits included Kachu sak (*Colocasia antiquorum*) (0.09–3.99 mg/kg, n = 9), potatoes (*Solanum tuberisum*) (0.07–1.36 mg/kg, n = 5), and Kalmi sak (*Ipomoea reptoms*) (0.1–1.53 mg/kg, n = 6). Alam and Rahman (2003) found that As accumulation in rice differ from variety to variety and the quantity of accumulated As decreases gradually from root to shoot. From their results, the As concentrations were 0.0, 0.052, 0.29 and 15.8 mg kg^{-1} in rice grain, husk, leaf and stem, respectively. They also observed that variations in As could depend on many factors such as rice variety, use of irrigation water, soil quality, fertilizer applied etc. Islam *et al*. (2004) conducted a pot experiment with As rich irrigation water on *Boro* (Cv. BRRI dhan29) and residual effect on T. Aman (Cv. BRRI dhan33) rice and found that the concentration of As in rice grain or straw of both the rice increased significantly with increasing As concentration in irrigation water, although the values of grain As was always below the maximum permissible limit (1.0 ppm). Khan *et al*. (2010) observed that As concentration in rice straw (2.64 to 12.52 µg g^{-1}), husk (1.20 to 2.48 µg g^{-1}) and grain (0.22 to 0.81 µg g^{-1}) increased with increasing As addition whether via irrigation water or direct addition to soil. According to them, the As concentrations in rice grain, straw and husk followed the order grain < husk < straw and the ratio of concentrated As in straw: grain was ∼ 20 – 24 with BRRI dhan29 and ∼ 12 – 16 with BRRI dhan 33; moreover, the concentrations in rice husk was 3 – 6 times that in grain, with no clear difference between the varieties. In another study the authors found that the concentration of As in rice straw (1.4-17.2 µg g^{-1}) was 5 – 62-fold higher than that in grain (0.24-1.09 µg g^{-1}), when rice grown in different levels of As concentrated soils, collected from 3 different districts (Noakhali, Naraynganj and Faridpur) of Bangladesh (Khan *et al*., 2010). Das *et al*. (2003) also reported that the concentration of As in root, shoot and rice-grain of paddy were different. Roots of paddy accumulated the highest As followed by shoot and rice-grain. The mean As in rice grain (0.23 mg kg^{-1}) is 6 times less than in shoot and 10 times less than in the root. Abedin *et al*. (2002) conducted a greenhouse pot experiment with arsenic-contaminated irrigation water on the growth and uptake of arsenic into rice grain, husk, straw and root. They observed that As concentrations in all plant parts increased with increasing arsenate concentration in irrigation water following a sequence of root > straw > husk > grain. Bhattacharya *et al*. (2012) were investigated arsenic contaminated irrigation water and paddy field soil to assess the accumulation of arsenic and its distribution in the various parts (root, straw, husk, and grain) of rice plant. Results showed that the paddy soil get contaminated from the irrigation water and thus enhancing the bioaccumulation of arsenic in rice plants.

CHAPTER III

MATERIALS AND METHOD

Three experiments were carried out to evaluate the effect of industrial wastewater and arsenic polluted irrigation water on metal accumulation in rice crop grown in the contaminated soils of selected industrial and agricultural land areas. The details of the materials and methods followed during the course of this investigation are presented in this chapter.

3.1 Effect of different fertilizers and manures on yield and metal accumulation in rice grown under two polluted soils of Gazipur industrial areas

3.1.1 Study location, plant materials and growth conditions

A pot experiment was designed at the net house of the Department of Soil Science, Sher-e-Bangla Agricultural University (SAU), Dhaka, during the month of December 2015 to November 2016. The study site is 8.2 m above the mean sea level and characterized by a sub-tropical climate with hot summer and mild winter. The minimum and maximum temperatures of the research area fluctuated between 7–23°C and 28–39°C, respectively, during the experimental period. BRRI dhan 28 and BRRI dhan 33, high yielding *Boro* and T. Aman rice varieties, respectively were used in the present study. Three different industrially polluted soils were collected from Gazipur industrially polluted areas. The physico-chemical properties of the initial soil samples were determined and presented in Table 1.

Table 1. Soil texture, OM, pH, total Cd, Pb, Zn and As concentrations of three initial soils used in experiment

Soils	**Cd Conc. (ppm)**	**Pb Conc. (ppm)**	**Zn Conc. (ppm)**	**As Conc. (ppm)**	**pH**	**%OC**	**Soil texture**
S_1 (Non-polluted Soils of industrial area)	0.52	2.82	61.0	1.34	6.4	0.76	Silt loam
S_2 (Industrially polluted soil-1)	3.86	5.46	71.0	3.96	6.5	0.82	Silt loam
S_3 (Industrially polluted soil-2)	4.42	6.23	73.0	4.56	6.4	0.83	Silt loam

3.1.2 Experimental design

The experiment was laid out in a two factor Randomized Complete Block Design with three replications. Two industrially polluted soils (S_2 and S_3) and one non-polluted soil (S_1) of same area were used as factor A. Further, the three different doses of fertilizers viz. T_0, T_1 and T_2 comprised the three different fertilizer levels (Control, $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF) and $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6 ton cowdung/ha) of factor B. As, such there were nine treatment combinations in the present study. The pots were filled up with three different types of polluted soils and treatment wise (T_0S_1, T_1S_1, T_2S_1, T_0S_2, T_1S_2, T_2S_2, T_0S_3, T_1S_3 and T_2S_3) doses of fertilizers and manures were applied and intermixed with the soils. More specifically, the required amount of manures (cowdung), TSP, MoP, gypsum, zinc sulphate and one third of urea were mingled with the soil by considering the fertilizer treatments and weight of soils in the pot (BARC, 2012). Rest amount of urea were applied at two splits during early vegetative phase and flowering phase.

The nine-treatment combinations are-

T_0S_1: Non-polluted soil × Control

T_1S_1: Non-polluted soil × $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF)

T_2S_1: Non-polluted soil×$N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6-ton cowdung ha^{-1}

T_0S_2: polluted soil-1× Control

T_1S_2: polluted soil-1× $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF)

T_2S_2: polluted soil-1× $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6-ton cowdung ha^{-1}

T_0S_3: polluted soil-2× Control

T_1S_3: polluted soil-2× $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF) and

T_2S_3: polluted soil-2× $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6-ton cowdung ha^{-1}

It is important to note that after harvesting of boro rice; the T. Aman rice (cv. BRRI dhan 33) was grown in the same pots to evaluate the residual effects of manures and/or fertilizers that were applied for the previous boro rice. The soils of the pots were again intermixed with three different gradients of fertilizers and/or manures. The lower amount of fertilizer and manure were applied in T. Aman according to the recommended dose of chemical fertilizer ($N_{120}P_{20}K_{60}S_{10}Zn_{1.5}$) and 6-ton cowdung ha^{-1} manure.

Healthy rice seeds were surface-sterilized in 5% (v/v) sodium hypochlorite solution containing 0.2% (v/v) for 30 minutes followed by five times washed with distilled water (dH_2O). Subsequently, the surface-sterilized seeds were incubated in dH_2O at 26°C in the dark for four days. Germinated seeds were then transferred to earthen pots (30 cm in height and 34 cm in diameter) containing 17 kg of puddled soils. However, two seedlings were transplanted in each pot.

3.1.3 Intercultural operation

Traditional irrigation i.e. continuous flooding (2-3 cm water) was imposed to the pots. Other cultural management practices, including weeding, drainage, pesticides application etc. were done as and when needed.

3.1.4 Harvesting and data collection

After harvest of each boro and T. Aman rice, the yield and yield components were recorded. The harvested crop from each pot was bundled separately and spread on the wooden table for 4-5 days for air drying. After that, grain and straw yields per pot was recorded. Plants of one hill from each core were measured and averaged to record the yield contributing characters. Plant height (cm) was measured from the ground level to the top of the panicle. The number of effective tillers of a hill for each core was counted. Panicle length (cm) was measured from basal node of the rachis to the apex. The number of grains per panicle from all fertile tillers was counted. The weight of the thousand grains from each core was recorded. The grain and straw yields (g core^{-1}) were dried and weighed. Then the collected rice grain samples were oven dried at 70°±5°C for 72 hours. The rice grain samples were ground with an electrical grinder for chemical analysis.

3.2 Effect of irrigation and different sources of fertilizer and manure on the yield of rice and accumulation of metals in rice grown in arsenic contaminated soils of Naraynganj

Effect of fertilizer and irrigation on the yield attributes and yield of boro rice

3.2.1 Study location, plant materials and growth conditions

The experimental location, test crops and growth conditions of the current study were designed following the procedures of experiment 1. The soils used in the present study were collected from the arsenic (As)-contaminated area of Naraynganj district, where rice fields were predominantly irrigated with shallow tube well (STW) water for a long time, which presume to rich in As. However, initially soil samples were collected from five different locations of Naraynganj district and then subjected to lab analysis to determine the As level by using Atomic Absorption Spectrophotometer (AAS). Soils collected from the Fatehpur regions of Naraynganj district have reported to rich in As among the collected soil samples that are frequently irrigated with STW. Finally, 500 kg of soils were collected from the As-rich soils of Fatehpur regions to fill-up the experimental pots and the physico-chemical properties of the initial soil samples were presented in Table 2.

Table 2. The texture, OC, pH, total Cd, Pb, Zn and As concentration in arsenic contaminated paddy field soil

Soils	**Cd Conc. (ppm)**	**Pb Conc. (ppm)**	**Zn Conc. (ppm)**	**As Conc. (ppm)**	**pH**	**OC (%)**	**Soil texture**
Arsenic contaminated paddy field soil	1.26	0.65	80.17	20.0	6.9	1.21	Silt loam

3.2.2 Experimental design and treatment

The experiment was laid out in a two factor Randomized Complete Block Design (RCBD) with three replications. Five different dosages of fertilizers and/or manures viz. $T_{0,}$ T_1, $T_{2,}$ T_3 and T_4 were applied as Factor A. Further, the two different types of irrigation methods viz. I_1 and I_2 comprised the two different levels of factor B. As, such there were ten treatment combinations in the present study. The pots were filled up with As-rich soils and five different gradients of fertilizers and/or manures were applied as per treatment combinations. The fertilizers were applied and mixed to the pots according to the procedures of experiment 1. However, each dose of fertilizers treated pots were classified as two sets, where one sets in each case were irrigated following alternate wetting and drying method, and other sets were irrigated following traditional method (kept 2-3 cm water).

The ten-treatment combinations are:

T_0 I_1: Control × Traditional irrigation

T_1 I_1: ($N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF) × Traditional irrigation

T_2 I_1: $N_{150}P_{60}K_{60}S_{20}Zn_{3.0}$× Traditional irrigation

T_3 I_1: $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6-ton cowdung/ha × Traditional irrigation

T_4 I_1: $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 5-ton compost/ha× Traditional irrigation

T_0 I_2: Control × alternate wetting drying

T_1 I_2: ($N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF) × alternate wetting and drying

T_2 I_2: $N_{150}P_{60}K_{60}S_{20}Zn_{3.0}$ × alternate wetting drying

T_3 I_2: $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6-ton cowdung/ha × alternate wetting and drying, and

T_4 I_2: $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 5-ton compost/ha × alternate wetting and drying.

It is important to note that after harvesting of boro rice; the T. Aman rice (cv. BRRI dhan 33) was grown in the same pots to evaluate the residual effects of manures and/or fertilizers that were applied for the previous boro rice. The soils of the pots were again intermixed with five different gradients of fertilizers and/or manures. The lower amounts of fertilizer were applied in T. Aman according to the recommended dose of chemical fertilizer ($N_{120}P_{20}K_{60}S_{10}Zn_{1.5}$). Similarly, two irrigation levels were maintained when irrigation was applied during T. Aman growing period.

3.2.3 Intercultural operations

Cultural management practices, including weeding, drainage, pesticides application etc. were done as and when needed.

3.2.4 Determination of growth and yield-attributes of rice

Harvesting of both rice varieties, including boro and T. Aman were done when the spikelet turned yellow brown color as an indication of the maturity of the grains (Begcy *et al.*, 2018). After harvesting, the growth and yield-attributes, including plant height, total number of effective tillers, number of effective tillers per hill, panicle length, filled and unfilled grains per panicle, 1000 grain weight, straw and grain yields were recorded. Then the collected rice grain samples were oven dried at $70^{\circ}\pm5^{\circ}$C for 72 hours. The rice grain samples were ground with an electrical grinder for chemical analysis.

3.2.5 Determination of heavy metal concentrations in grain

The concentration of heavy metals and metalloid (As) in the collected grain samples were determined following the methods.

Total concentrations of Pb, Cd, Ni and Cr in soil samples were determined by using an atomic absorption spectrophotometer (Model: novAA400P, Brand: analytic jena), equipped with single elements hollow-cathode lamps at the wavelengths of 283.3, 228.8, 232.0 and 357.9 nm, respectively. The instrument was operated at maximum sensitivity with an air-acetylene flame. Lamp intensity and bandpass were used according to the manufacturer's recommendations. For the determination of total heavy metals concentration, exactly 0.5 g of rice sample was grained and digested with aqua regia (HNO_3: HCl = 1: 3). All chemicals and reagents were of analytical reagent grade quality (Merck, Germany). Before use, all glass and plastic ware were soaked in 14% HNO_3 for 24 hrs. The washing was completed with deionized water.

For As, 0.5 g of rice sample was grained and taken into the appropriate digestion tube. Then 10 mL of 1:1 HNO_3: H_2O_2 was added in the tube and the slurry was mixed and covered with a vapor recovery device. Then the sample was heated without boiling at $95 \pm 5^{\circ}C$ for 10-15 minutes. Then the sample was allowed to cool and 5 mL 12M HNO_3 was added and the cover was replaced and heated at $95 \pm 5^{\circ}C$ for 30 minutes. This step (addition of 5 mL conc. HNO_3) was repeated until no brown fumes were given off by the sample. After completion of the reaction with HNO_3 the sample was allowed to cool. Then 2 mL of water and 3 mL of 30% H_2O_2 was added and the vessel was covered with a vapor recovery device and was returned to the heat source for warming and peroxide reaction started. Heat was continued until effervescence: subsides and cooled the vessel. Then 1 mL of 30% H_2O_2 was added in the aliquots with warming until the effervescence was minimal or until the general sample appearance is unchanged. After cooling, the digest sample was diluted to 50 mL volume with water. Particulates of the digest were removed by filtration. Then the sample was ready for arsenic analysis. Total arsenic content in soil was determined from the digest by flow injection hydride generation atomic absorption spectroscopy (HG-AAS Model: novAA400P, Brand: analytic jena).

3.2.6 Soil analysis for chemical properties, essential nutrients and heavy metals

Soil samples were collected from each pot at three different points and then mixed to form a one composite sample for each replication. The samples were sealed in plastic bags and transported to the lab, and then plant detritus and other fragments were removed. After air-dried, the soil samples were ground and passed through a 2 mm sieve for analysis of pH, organic matter, essential minerals and concentration of heavy metals.

Soil pH

The soil pH was determined in 1: 2.5 soil: water suspension by potentiometric method using glass electrode pH meter (Jackson, 1973).

Soil Organic Matter

Soil organic matter was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982).

Total Nitrogen

Total nitrogen was determined by Micro-Kjeldehl method (Jackson, 1973). Total N content of soil was determined following the micro-Kjeldahl method. The soil was digested with H_2O_2 and conc. H_2SO_4 in presence of a catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Se in the ratio of 10: 1: 0.1) and the nitrogen in the digest was determined by distillation with 40% NaOH followed by titration of distillate trapped in H_3BO_3 with 0.01N H_2SO_4 (Page *et al.*, 1982).

Available Phosphorus

Phosphorus was extracted from soil samples by the sodium bicarbonate (0.5 M, pH 8.5) method according to Olsen *et al*. (1954) and determined by the ascorbic acid–molybdenum blue method at wavelength of 660 nm in Spectro-photometer as described by Jackson (1973).

Available Sulphur

Available S was determined by 0.15% $CaCl_2$ extraction method (Page *et al.*, 1982).

Available Potassium, Calcium and Magnesium

The exchangeable cations like potassium (K), calcium (Ca) and magnesium (Mg) were extracted with 1 N ammonium acetate and determined using the Flame photometer (Jackson, 1973). Available sulfur was determined turbidimetrically using barium chloride and reading was taken by Double Beam Spectrophotometer (Chesnin and Yien, 1951).

Heavy Metal Determination

Total concentrations of Pb, Cd, Ni and Cr in soil samples were determined by using an atomic absorption spectrophotometer (Model: novAA400P, Brand: analytic jena), equipped with single elements hollow-cathode lamps at the wavelengths of 283.3, 228.8, 232.0 and 357.9 nm, respectively. The instrument was operated at maximum sensitivity with an air-acetylene flame. Lamp intensity and bandpass were used according to the manufacturer's recommendations. For the determination of total heavy metals concentration, exactly 1.00 g of powdered soil sample was digested with aqua regia (HNO_3: HCl = 1: 3). All chemicals and reagents were of analytical reagent grade quality (Merck, Germany). Before use, all glass and plastic ware were soaked in 14% HNO_3 for 24 hrs. The washing was completed with deionized water.

Arsenic Analysis

One-gram soil sample was taken into the appropriate digestion tube. Then 10 mL of 1:1 HNO_3: H_2O_2 was added in the tube and the slurry was mixed and covered with a vapor recovery device. Then the sample was heated without boiling at $95 \pm 5^{\circ}C$ for 10-15 minutes. Then the sample was allowed to cool and 5 mL 12M HNO_3 was added and the cover was replaced and heated at $95 \pm 5^{\circ}C$ for 30 minutes. This step (addition of 5 mL conc. HNO_3) was repeated until no brown fumes were given off by the sample. After completion of the reaction with HNO_3 the sample was allowed to cool. Then 2 mL of water and 3 mL of 30% H_2O_2 was added and the vessel was covered with a vapor recovery device and was returned to the heat source for warming and peroxide reaction started. Heat was continued until effervescence: subsides and cooled the vessel. Then 1 mL of 30% H_2O_2 was added in the aliquots with warming until the effervescence was minimal or until the general sample appearance is unchanged. After cooling, the digest sample was diluted to 50 mL volume with water. Particulates of the digest were removed by filtration. Then the sample was ready for arsenic analysis. Total arsenic content in soil was determined from the digest by flow injection hydride generation atomic absorption spectroscopy (HG-AAS Model: novAA400P, Brand: analytic jena).

Determination of Cu, Mn and Fe for soil

Ten grams of soil was taken in a plastic pot then 20 ml DTPA was added and shake for 2 hours in rotary shaker. Then filtered into a conical flask and transferred into a test tube and sealed with aluminum foil. After that took reading form Atomic absorption Spectrophotometer (Cu: 327.40 nm, Mn: 403.1 nm, Fe: 248.33 nm).

For preparation of DTPA solution for 1000 ml - took 1000 ml distilled water in a beaker and added 14.02 g of Triethanolamin and added 1.96 g of DTPA powder and added 1.47 g of $CaCl_2$. Then adjusted pH at 7.3 with 10% HCL and finally made volume up to the 1000 ml.

Calculation:

Cu (ppm): (S-B) × df × f

Mn (ppm): (S-B) × df × f

Fe (ppm): (S-B) × df × f

df: $\frac{20\ (DTPA)}{10\ g\ soil} \times \frac{volume\ level}{amount\ of\ aliquot\ taken}$

f: $\frac{mean\ standard}{mean\ absorption}$

3.2.7 Statistical analysis

The collected data were analyzed using a two-way analysis of variance (ANOVA), and the significant differences between treatments were denoted by different alphabetical letters according to the least significant difference (LSD) test at $p < 0.05$ using STATISTIX 10 software. All the data were represented in the tables were the means ± standard errors (SEs) of three independent replicates for each treatment.

3.3 Assessment of Toxic Metals in Wastewater on the Livelihood and Food Security of the Local People around the Industrial Area

3.3.1 Location of the study area

To get the ground truth information to better understand the enigmatic effects of industrial effluents in the adjacent area, a questionnaire survey has been conducted in one upazila of Gazipur district, including Gazipur sadar (Figure. 1). The area of Gazipur sadar is 141.19 sq. km. It is bounded by Sreepur upazila on the north, Kaliganj upazila on the east, Uttar Thana on the south and 30 number ward of Gazipur city corporation on the west. Total population of the Upazila are 194297, of which male 101638 and female 92659. Population density of Gazipur sadar is 1211 per square kilometer. The target areas in the upazila are Bangla bazar, Vawal Mirzapur, and Salna, where various small-scale factories exist. The main industries are different in each area: textiles, dyes, batteries, metallurgy and ceramics in Bangla bazar; pharmaceuticals, agrochemicals, fabric printing, poultry feed, and fish feed in Vawal

Mirzapur and garments industries in Salna. In all the areas, industrial wastewater is discharged from factories into nearby irrigation canals throughout the year.

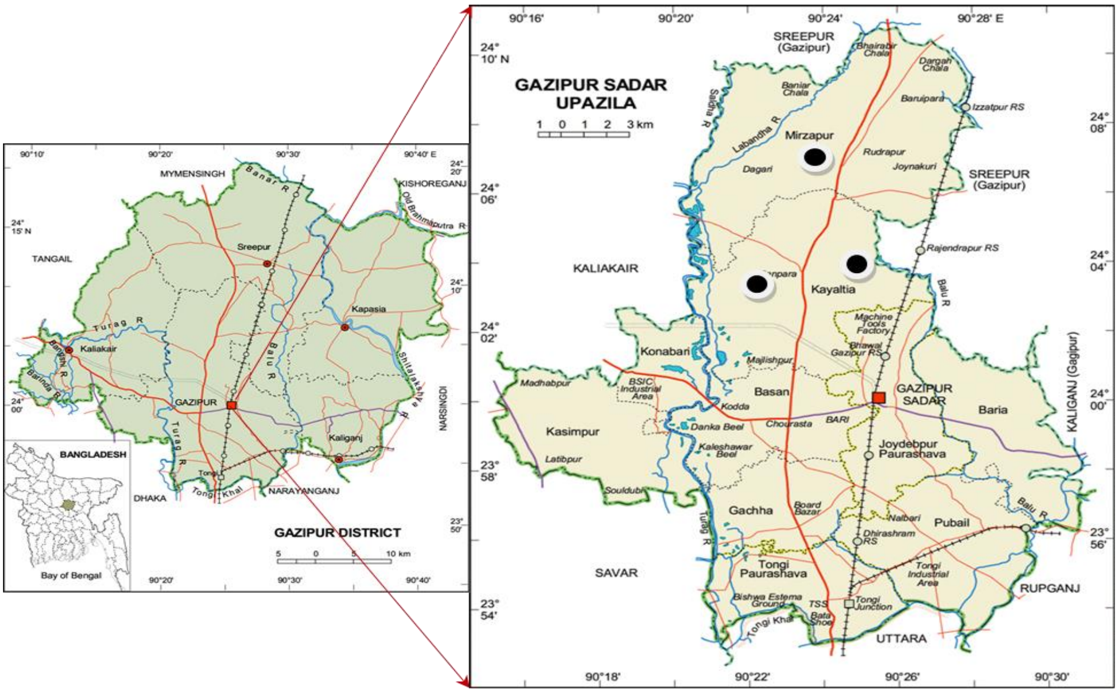

Fig. 1. Study area

● Indicate surveyed area

3.3.2 Population and sampling technique

Farmers usually grow rice and/or vegetables adjacent to the industrial area where the study was conducted. A total of fifty respondents were selected randomly from the three areas of the studied upazila.

3.3.3 Tools and methods of data collection

For collecting primary data at farm level, a pre-designed interview schedule (Appendix 1) was developed with balanced combination of both closed and open-ended questions, and the same was pre-tested before finalization. Participatory Rural Appraisal (PRA) tools and techniques like Focus Group Discussion (FGD) and Direct Observation were also applied for triangulation of data. According to SEAGA (2002), focus group discussion is a social survey method that identifies the reason(s) for existing activities and behavior patterns of a particular activity, identifies changes from the men or women perspectives, the obstacles to change, and such change might be facilitated. Direct observation is a good way to cross-check information. It was conducted in all the study locations during the entire period of data collection.

3.3.4 Development of data gathering questionnaire

A research questionnaire is usually deemed to be valid when the objectives of the study are reflected in the instrument. In order to collect relevant information from the respondents, an interview schedule was carefully designed keeping the objectives of the study in view. The questionnaire contained both open and closed form questions. In the interview schedule, the questions were so arranged that the prior question had a continual effect on the following questions. It helped the interviewee to remain focused on responding the questions until the last one came in. It also helped the respondents to continue their pursuit without feeling boredom.

3.3.5 Data collection procedure

Data were collected during the months from November 2018 to December 2018 by the researcher herself. To get the valid and pertinent information, the researcher tried to make all possible efforts to explain the purpose of the study to the respondents. While starting interview, the researcher took utmost care to establish rapport with the respondent farmers, so that they do not feel hesitate or hostile to furnish proper responses to the questions of the instrument. All possible precautions were taken to avoid biasness and to maintain fidelity of responses. While interviewing, local dialect was used that helped both the researcher and the interviewees to understand each other. The questions were explained and clarified whenever any respondent farmers felt difficulty in understanding properly. Care was taken not to use technical jargon, not to feed answer to farmers by teaching them terminology or using names. Where necessary questions were asked in several different ways until the researcher was sure that farmer understood the questions. If farmer’s response was not clear enough what he intended to mean, supplementary questions were asked for further clarification.

3.3.6 Measurement of selected variables

The selected variables were age, education, family size, secondary occupation, farm size, annual income, distance-induced effects on modification of soil and water properties, impact of industrial effluent contamination in rice production, suitability of color and odor of soil, surface water and ground water for daily usages, impacts of industrial effluent on rice yield and rice quality, and problems confronted by the respondents.

Age

Age of the farmers was recorded on the basis of their chronological years from their date of births to the time of interviewing and was rounded to the nearest whole number. The age of an individual is one of the most important factors pertaining to his personality make up, which may play an important role in his perception. A score of one (1) was assigned to each year of age. It was measured in complete years as reported by a respondent. For example, a respondent of 23 years of age scored 23. For the analysis purposes, age of the respondents was broken into three categories according to Haider (2010):

Categories	**Score**
Young	Up to 35 years
Middle	36 to 50 years
Old	More than 50 years

Education

Education of a respondent was measured in terms of degree he/she obtained in formal education system (i.e., primary school, high school). A score of zero (0) was assigned for no education at all, 1 for can sign only, 2 for primary level, 3 for secondary and 4 for higher secondary and above. The respondents were classified into the following categories according to Ghosh and Hasan (2013).

Sl. No	**Level of education**	**Score**
1	No education at all	0
2	Can sign only	1
2	Primary level education (Class I- Class V)	2
3	Secondary level education (VI-X)	3
4	Higher Secondary and above (Above X)	4

Family size

Family size referred to the total number of members including the respondent himself, spouse, children and other permanent dependents who lived together as family unit. Family size was operationally measured by assigning a score of one (1) for each member of the family who jointly live and eat together. Family size of a respondent was measured in terms of actual number (all dependents) of members in his family (including himself) during the interview period.

The families were divided into three categories:

Categories	Number of members in family
Small	Up to 4 members
Medium	5-8 members
Large	More than 8 members

Secondary occupation

In society, occupations are perceived to bring greater economic, social, or prestige rewards than others. Occupation of respondents acts as a key determinant of annual income. However, apart from farming as a key profession; based on occupation nature, the respondents were classified into four categories such as driving, fishing, business, and day labor as a basis of secondary occupation.

Farm size

Farmland is the most valuable asset among rural population of Bangladesh. Economic, social and political status of the villagers depends on it. Farm size influences on many personal characteristics of a farmer. Farm is a tract of land possessed by an individual for the purpose of obtaining agricultural production. In most cases farm size is positively and significantly related to the adoption of improved farm practices. The actual area under cultivation in hectare was taken as measurement of farm size (Mazumder, 2004). The farm size of a respondent was measured by asking the respondent to mention area of land under his possession. The following formula was used to measure farm size of the respondents.

Total land possessed

(TLP) = a+b+1/2(c+d) +e-f)

TLP= Total land possessed

a= Homestead area including pond

b= Own land under own cultivation

c= Area shared in borga by the respondents

d= Area shared out borga by the respondents

e= Area leased in by the respondents

f= Area leased out by the respondents

Based on the information of total land possessions, farm size of the respondents was classified into 5 groups (Anonymous, 2011).

Categories	**Volume of land (in ha)**
Landless	Up to 0.2 ha
Marginal	0.201-0.60 ha
Small	0.601-1.00 ha
Medium	1.01-3.00 ha
Large	More than 3.00 ha

Annual income

The income of a respondent was measured in taka on the basis of the total yearly earnings of his /her family from agricultural and non-agricultural sources. To determine agricultural income of a respondent, yields of all the crops produced in the immediate previous year of the study were converted into cash according to the market price. The values of other farming products encompassing livestock, poultry, fisheries etc. were taken into consideration. Earnings from other non-farming activities (Services, Business, Labor and others) of the respondents and other members of his family (if any) were also calculated. Yearly income from farm and non-farm activities were added together to obtain the total income of a respondent and was categorized as following Hossain *et al.* (2002) and Arifin (2011).

Categories	Family income (in Taka)
Low	≤ Tk. 130,000
Medium	Tk. 130,000 – 200,000
High	Above Tk. 200,000

Perception towards injurious impacts of industrial effluent on rice production

Perception of the rice producing farmers about the negative impacts of industrial effluents in rice production was evaluated by seeking rice-growers opinion against 10 attitudinal statements included in the interview schedule. There was scope of giving sole percentage respondents opinion in each attitudinal category, which includes strongly agreed, agreed, undecided, disagreed, and strongly disagreed, but the sum of five attitudinal categories should not exceed or lower than 100% against each statement.

Perception of the farmers regarding soil color and odor change before and after industrialization

Respondents were asked about the changes of color and odor of the soils observed before and after industrial exploration against four indicators, including very good, good, bad and very bad.

Perception of the farmers regarding ground- and surface-water color and odor change before and after industrialization

Respondents were asked about the changes of color and odor of the ground and surface water before and after industrial exploration for different types of usages, like domestic activities, irrigation, bathing, drinking and cooking against four indicators, including very good, good, bad and very bad.

Perception towards injurious impacts of industrial effluent on rice yield

Farmers were asked about the extent of yield reduction (no, low, medium and high decrease) confronted when grow different seasons rice, including *Aus*, *Aman* and *Boro* in industrially contaminated area.

Perception towards injurious impacts of industrial effluent on rice quality

Farmers were asked about the size and shape, taste, color, odor and market value of rice before and after the establishment of industries against four indicators for each, which includes very good, good, bad and very bad.

3.3.7 Problems triggered by industrial effluents

Problem means something that is difficult to deal with or a situation regarded as unwelcomed. Respondents confront different types of difficulties, when they cannot solve their problems, they usually discuss with others, and seek help from different sources. A 16-item measuring scale was used to determine the problem confrontation of the respondents. Each respondent was asked about the extent of his problem confrontation against each of the statements. The score of problem confrontation of each respondent ranged from 1 to 48. Nonetheless, the PCI for each of the problem ranged from 1 to 150, 1 indicating less problem faced by the respondents and 150 indicating the highest level of problems faced by the respondents.

The problem confrontation index (PCI) was calculated by multiplying the frequency count of each of the cell of a scale of extent of problem with its corresponding weights such as 3 for high, 2 for medium, and 1 for low. By adding all the values of each cell together, the score of PCI was calculated.

$$PCI = (Ph \times 3 + Pm \times 2 + Pl \times 1)$$

Where, PCI=Problem confrontation index,

Ph= High problem,

Pm= Medium problem and

Pl =Less problem

3.3.8 Data compilation and analysis

After compilation of field survey, data from all the interview schedules were coded, compiled, tabulated and analyzed in accordance to the objectives of the study. In this process, all the responses in the interview schedule were given numerical coded values. Local units were converted into standard units and qualitative data were converted into quantitative ones by means of suitable scoring system whenever necessary. The responses to the questions in the interview schedules were transferred to a master sheet to facilitate tabulation. The SPSS/PC+ computer program (Statistical Package for Social Sciences) was used to perform data analysis. Descriptive statistical measures like range, mean, number and percentage distribution, standard deviation were used to describe and interpret the data. Throughout the study 5 percent (0.05) level of probability with an accompanying 95 percent confidence level was used as a basis for rejecting or accepting the null hypothesis.

CHAPTER IV

RESULTS

4.1 Effect of different fertilizers and manures on yield and metal accumulation in rice grown under two polluted soils of Gazipur industrial areas

4.1.1 Effect of polluted soils on the growth and yield of boro rice

The yields and yield-contributing attributes of boro rice were influenced significantly with the variations of polluted soils (Table 3.1). In respect of polluted soils, maximum values of plant height (142.18 cm), total number of tillers hill^{-1} (57.11), number of effective tillers hill^{-1} (49.89), length of panicle (32.54 cm), filled and unfilled grains panicle^{-1} (275.31 and 220.80, respectively) were recorded in S_1 soil. Whereas, the lowest values of plant height (127.01 cm), total effective tillers number (30.56), the number of effective tillers hill^{-1} (25.78), length of panicle (26.68 cm), and filled and unfilled grains in panicle^{-1} (72.71 and 37.63) were recorded in S_3 treated pots. In respect of thousand grain weight, the highest and the lowest values were recorded in S_1 (20.33 g) and S_3 (16.78 g) treated pots, respectively. The grain and straw yields were significantly influenced by polluted soils. Maximum straw (151.24 g pot^{-1}) and grain yield (95.14 g pot^{-1}) were found in S_1 treated pots, whilst the minimum values of those parameters (64.03 and 32.42 g pot^{-1}, respectively) were observed in S_3 treated pots.

4.1.2 Effect of fertilizer treatments on the growth and yield of boro rice

In response to fertilizer effects, the highest values of plant height (139.12 cm), total number of effective tillers per pot (49.00), number of effective tillers per hill (43.33), filled and unfilled grains per panicle (233.73 and 133.46, respectively), straw- and grain-yields (123.54 and 77.15 g pot^{-1}, respectively) were recorded in T_2 treated pots, whilst the lowest values of those parameters (131.29 cm, 38.22, 33.78, 159.20, 79.09, 92.53 g pot^{-1} and 67.71 g pot^{-1}, respectively) were noted in T_0 treated pots. However, maximum length of panicle (30.08 cm) was recorded in T_2 treated pots, which was statistically similar to T_1 treatment (29.32 cm), and minimum value (27.57 cm) was found in T_0 treated pots (Table 3.1). Thousand grain weight was significantly influenced among the treatments, and the highest and lowest values (19.00 and 17.72 g) were recorded in T_2 and T_0 treated pots, respectively, whereas, the highest value was statistically similar with the value obtained in T_1 treatment (18.72 g).

4.1.3 Interaction effects of fertilizer and polluted soils on the growth and yield of boro rice

The yield and yield parameters were varied significantly by the interaction effect of polluted soils and fertilizer treatments (Table 3). The plant height was significantly influenced by interaction effect of fertilizer and polluted soils. The highest and the lowest plant height (151.27 and 124.87 cm) were obtained in T_2S_1 and T_0S_3 treatment combinations, respectively. Maximum number of total tillers hill^{-1} (57.00) was recorded in T_2S_1, whilst the minimum number (28.33) was counted in both T_1S_3 and T_0S_3 treatment combinations. However, the higher number of effective tillers hill^{-1} (51.33) was found in T_2S_1 and the lower values (23.00 and 24.33) were observed in T_1S_3 and T_0S_3 treatment combinations, respectively. The highest and lowest panicle length (35.01 and 25.63 cm) were found in T_2S_1 and T_0S_3 treatment combinations, respectively, which were significantly varied from all other treatment combinations. Number of filled and unfilled grains panicle^{-1} differed significantly among the treatments, and the highest numbers (313.87 and 266.20, respectively) were recorded in T_2S_1 and the lowest numbers (24.00 and 23.07, respectively) were found in T_0S_3

treatment combination. Thousand grain weight was observed to be the highest (21.33 g) in both T_2S_1 and T_1S_1 treated pots, whereas it was the lowest (16.50 g) in both T_1S_3 and T_0S_3 treatment combinations. The grain and straw yields were significantly affected by the interaction of polluted soils and fertilizer treatments. The highest and lowest yields of straw (173.23 and 55.43 g pot^{-1}) were recorded in T_2S_1 and T_0S_3 treatment combinations, respectively. However, maximum grain yield (96.40 g pot^{-1}) was obtained in T_2S_1 and the minimum (22.57 g pot^{-1}) was found in T_0S_3. The second highest grain yield (94.63 g pot^{-1}) was found in T_1S_1 which was statistically similar to T_0S_1 treatment combination.

Table 3. Yield and its attributes of boro rice as influenced by the main and interaction effects of polluted soils and different fertilizer treatments

Treatments	**Plant height (cm)**	**Total number of tillers hill^{-1}**	**Effective tillers hill^{-1} (No.)**	**Panicle length (cm)**	**Filled grains panicle^{-1} (No.)**	**Un-filled grains panicle^{-1} (No.)**	**1000 grain wt. (g)**	**Straw yield (g pot^{-1})**	**Grain yield (g pot^{-1})**
Polluted soils type									
S_1	142.18a	52.78a	47.00a	32.54a	275.31a	220.80a	20.33a	151.24a	95.14a
S_2	134.07b	43.33b	37.89b	27.74b	218.84b	66.04b	18.33b	113.52b	87.25b
S_3	127.01c	30.56c	25.78c	26.68c	72.71c	37.63c	16.78c	64.03c	32.42c
SE	0.35	0.49	0.54	0.37	0.46	0.39	0.44	0.34	0.39
Fertilizer gradients									
T_0	131.29c	38.22c	33.78c	27.57b	159.20c	79.09c	17.72b	92.53c	67.71c
T_1	132.84b	41.89b	36.44b	29.32a	173.93b	111.93b	18.72a	112.72b	69.96b
T_2	139.12a	46.56a	40.44a	30.08a	233.73a	133.46a	19.00a	123.54a	77.15a
SE	0.35	0.49	0.54	0.37	0.46	0.39	0.44	0.34	0.39
Fertilizer gradients × Polluted soils type									
$T_0 \times S_1$	136.73c	49.00c	42.00c	29.53c	254.87c	162.33c	18.33b	127.53c	94.40b
$T_0 \times S_2$	132.27d	37.33e	36.33e	27.56d	198.73f	51.87f	18.33b	94.63f	86.17d
$T_0 \times S_3$	124.87g	28.33g	23.00g	25.63e	24.00i	23.07i	16.50c	55.43i	22.57g
$T_1 \times S_1$	138.53b	52.33b	47.67b	33.10b	257.20b	233.87b	21.33a	152.97b	94.63b
$T_1 \times S_2$	133.4d	45.00d	37.33e	27.75d	222.93e	59.40e	18.33b	122.10e	86.83d
$T_1 \times S_3$	126.6f	28.33g	24.33g	27.10d	41.67h	42.53h	16.50c	63.10h	28.40f
$T_2 \times S_1$	151.27a	57.00a	51.33a	35.007a	313.87a	266.20a	21.33a	173.23a	96.40a
$T_2 \times S_2$	136.53c	47.67c	40.00d	27.93d	234.87d	86.87d	18.33b	123.83d	88.75c
$T_2 \times S_3$	129.57e	35.00f	30.00f	27.31d	152.47g	47.30g	17.33bc	73.57g	46.30e
SE	0.60	0.81	0.93	0.63	0.79	0.68	0.76	0.58	0.67
CV (%)	0.55	2.35	3.08	2.68	0.51	0.77	5.02	0.65	1.15

In a column, figures having similar letter(s) do not differ significantly at 5% level, whereas figures with dissimilar letter(s) differ significantly. S_1 –Non-polluted Soil, S_2 –Polluted Soil 1, S_3 –Polluted Soil 2, T_0 –Control, T_1 – $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF), T_2 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6 ton cowdung/ha.

4.1.4 Effect of polluted soils on the growth and yield of T. Aman rice

Analysis of variance indicated significant influences of main and interaction effects of polluted soils and different fertilizer doses on yield and yield-contributing attributes of T. Aman rice (Table 3.2). Main effect of polluted soils exhibited the maximum plant height (143.83 cm), the total number of effective tillers hill^{-1} (50.44) and number of effective tillers hill^{-1} (44.00) in S_1 treatment. Whereas the lowest values of those parameters (126.24 cm, 28.33 and 21.89, respectively) were found in S_3 treatment. The highest panicle length (36.99 cm) was found in S_1 treatment, and lowest value (26.77 cm) in S_3 treatment, which was statistically similar to S_2 treatment (27.74 cm). Maximum thousand grain weight (22.08 g) was recorded in S_1 soil and the minimum (17.88 g) was observed in S_3 treatment. Filled and unfilled grains panicle^{-1} were found maximum in S_1 treatment (186.42, 136.58). Similarly, the grain (84.75 g pot^{-1}) and straw-yield (133.40 g pot^{-1}) were also found higher in the same S_1 soil. Whereas the lowest number of filled (109.45) and unfilled grains (102.75) panicle^{-1} as well as grain (27.98 g pot^{-1}) and straw-yield (53.92 g pot^{-1}) were noted in S_3 soil.

4.1.5 Effect of different fertilizer treatments on the growth and yield of T. Aman rice

In response to different doses of applied fertilizers, the tallest plant (139.48 cm), maximum number of effective tillers (44.67), maximum number of effective tillers hill^{-1} (37.33), highest panicle length (33.97 cm), maximum straw- and grain-yield (105.64 and 68.18 g pot^{-1}) were recorded in T_2 treated pots. In contrast, lowest plant height (131.26 cm), total number of tillers hill^{-1} (38.22), effective tillers per hill (28.44) and panicle length (27.58 cm) were found in T_0 treated pots. Likewise, the lowest straw yield (95.12 g pot^{-1}) and grain yield (54.39 g pot^{-1}) were also observed in the same treatment of T_0. On the other hand, the maximum number of filled and unfilled grains panicle^{-1} (159.62 and 129.80, respectively) were recorded in T_2 treatment. Whereas the minimum number of filled and unfilled grains panicle^{-1} (110.11 and 9.89, respectively) were counted in T_0 treated pots (Table 3.2). The highest thousand grain weight (20.79 g) was found in T_2 treated pots, which was followed by T_1 treatment (20.25 g) that was statistically similar to the thousand grain weight of T_2 treatment, whereas the lowest weight of thousand grains (19.50 g) was noticed in T_0 treated pots.

4.1.6 Interaction effects of fertilizer and polluted soils on the growth and yield of T. Aman rice

In case of interaction, effects between polluted soils and fertilizer treatments, all the parameters were influenced significantly (Table 4). Plant height was measured and the highest (153.30 cm) was found in T_2S_1 treatment combination and the lowest (124.78 cm) was recorded in T_0S_3 treatment combination followed by T_1S_3 (125.30 cm). The maximum total number of tillers hill^{-1} (54.33) was observed in T_2S_1 treatment combination. The second highest number of total tillers per hill (49) was found in T_1S_1 treatment combination, which was statistically similar to T_2S_2 and T_0S_1 treatment combinations, whereas the minimum (25.00) was found in T_0S_3. The highest number of effective tillers hill^{-1} (50.00) was found in T_2S_1 treatment combination and the lowest number of effective tillers per hill (20.67) was recorded in both T_0S_3 and T_1S_3 treatment combinations. The highest (46.43 cm) and the lowest (25.65 cm) panicle lengths were found in T_2S_1 and T_0S_3 treatment combinations, respectively. However, the maximum number of filled grains panicle^{-1} (190.53) was observed in T_2S_1

treatment combination, which was statistically identical to T_1S_1 (188.20) treatment combination. The minimum number of filled-grains panicle^{-1} (94.21) was recorded in T_0S_3 treatment combination. The number of unfilled-grains panicle^{-1} was counted and the highest (167.20) was recorded in T_2S_1 treatment combination, whereas the lowest (102.13) was found in T_0S_3 treatment combination, which was statistically similar to T_1S_3 (102.39) and T_2S_3 (103.73) treatment combinations, respectively. The maximum weight of 1000 grain (22.83 g) was recorded in both T_1S_1 and T_2S_1 treatment combinations, and the minimum (17.33 g) was recorded in both T_0S_3 and T_1S_3 treatment combinations. The highest straw yield (136.80 g pot^{-1}) was noted in T_2S_1 treatment combination and the second highest (134.63 g pot^{-1}) was obtained in T_1S_1 treatment combination and the lowest straw yield (49.43 g pot^{-1}) was obtained in T_0S_3 treatment combination. The higher levels of added nutrient through inorganic fertilizer and manure in T_2S_1 treatment combination may increase the straw yield of rice. The maximum grain yield (88.75 g pot^{-1}) was obtained in S_1T_2 and the minimum (15.90 g pot^{-1}) was found in S_3T_0 treatment combination.

Table 4. Yield and its attributes of T. Aman rice as influenced by the main and interaction effects of polluted soils and different fertilizer treatments

Treatments	Plant height (cm)	Total number of tillers hill^{-1} (No.)	Effective tillers number hill^{-1}	Panicle length (cm)	Filled grains panicle^{-1} (No.)	Un-filled grains panicle^{-1} (No.)	1000 grain wt. (g)	Straw yield (g pot^{-1})	Grain yield (g pot^{-1})
Polluted soils type									
S$_1$	143.83a	50.44a	44.00a	36.99a	186.42a	136.58a	22.08a	133.40a	84.75a
S$_2$	133.73b	44.89b	33.00b	27.74b	152.51b	114.98b	20.58b	115.33b	67.58b
S$_3$	126.24c	28.33c	21.89c	26.77b	109.45c	102.75c	17.88c	53.92c	27.98c
SE	0.48	0.59	0.78	0.72	0.82	0.69	0.34	0.44	0.79
Fertilizer gradients									
T$_0$	131.26c	38.22c	28.44c	27.58c	135.60c	110.11c	19.50b	95.12c	54.39c
T$_1$	133.07b	40.78b	33.11b	29.95b	153.16b	114.40b	20.25a	101.89b	57.73b
T$_2$	139.48a	44.67a	37.33a	33.97a	159.62a	129.80a	20.79a	105.64a	68.18a
SE	0.48	0.59	0.78	0.72	0.82	0.69	0.34	0.44	0.79
Fertilizer gradients × Polluted soils type									
S$_1$ × T$_0$	137.70c	48.00b	40.00bc	29.53c	180.53b	119.00c	20.58b	128.77c	80.87c
S$_2$ × T$_0$	131.30e	41.67d	24.67e	27.56cd	132.07e	109.20d	20.58b	107.17e	66.40e
S$_3$ × T$_0$	124.78g	25.00g	20.67f	25.65d	94.21h	102.13e	17.33d	49.43h	15.90h
S$_1$ × T$_1$	140.50b	49.00b	42.00b	35.01b	188.20a	123.53b	22.83a	134.63b	84.63b
S$_2$ × T$_1$	133.40d	45.00c	36.67d	27.75cd	157.27d	117.27c	20.58b	118.93d	66.83de
S$_3$ × T$_1$	125.30g	28.33f	20.67f	27.10cd	114.00g	102.39e	17.33d	52.10g	21.73g
S$_1$ × T$_2$	153.30a	54.33a	50.00a	46.43a	190.53a	167.20a	22.83a	136.80a	88.75a
S$_2$ × T$_2$	136.50c	48.00b	37.67cd	27.93cd	168.20c	118.47c	20.58b	119.90d	69.50d
S$_3$ × T$_2$	128.64f	31.67e	24.33e	27.56cd	120.13f	103.73e	18.97c	60.23f	46.30f
SE	0.82	1.02	1.35	1.24	1.42	1.19	0.59	0.76	1.36
CV (%)	0.75	3.04	5.00	4.97	1.16	1.23	3.61	0.93	2.78

In a column, figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly. S$_1$ –Non-polluted Soil, S$_2$ –Polluted Soil 1, S$_3$ –Polluted Soil 2, T$_0$ –Control, T$_1$ – N$_{150}$P$_{30}$K$_{60}$S$_{20}$Zn$_{3.0}$ (100% RDCF), T$_2$ – N$_{75}$P$_{15}$K$_{30}$S$_{10}$Zn$_{1.5}$ (50% RDCF) + 6 ton cowdung/ha.

4.1.7 Effect of fertilizer and manure on the metal accumulation in rice grain

4.1.7.1 Effect of polluted soils on the metal accumulation in boro and T. Aman rice

The heavy metals concentrations in rice grain (Table 5) were significantly influenced by different polluted soils and application of fertilizer treatments imposed in both boro and T. Aman rice cultivation. The higher levels of Cd concentrations were noticed in boro rice grain in comparison to T. Aman rice grain. The effect of polluted soils on boro rice exhibited the highest and lowest concentrations of Cd (0.23 and 0.07 ppm) and Zn (38.05 and 15.90 ppm) in S_3 and S_1 treated pots, respectively. Like boro rice, in T. Aman, the maximum concentration of Cd (0.06 ppm), Zn (41.45 ppm) and Pb (0.13 ppm) were obtained in S_3 soil. The lowest concentrations of those metals (0.04 ppm for Cd, 0.06 ppm for Pb and 33.22 ppm for Zn) were recorded in S_1 soil treated pots of T. Aman rice grains. Higher levels of Cd and Zn were accumulated in the rice grains of polluted soils.

4.1.7.2 Effect of fertilizer on the metal accumulation in boro and T. Aman rice grain

The fertilizer treatment affected on heavy metal accumulation in boro rice grain (Table 5) The maximum concentrations of Cd (0.17 ppm) and Zn (31.72 ppm) were occurred in T_1 treated pots, where 100% chemical fertilizer was applied. However, the minimum Cd and Zn concentrations (0.11 and 23.82 ppm, respectively) were observed in T_0 treated pots. In case of T. Aman rice, metal accumulation varied significantly and the maximum (0.05, 38.52 and 0.10 ppm, respectively) and minimum (0.04, 35.55 and 0.09 ppm, respectively) values of Cd, Zn and Pb were found in T_1 and T_0 treatments, respectively.

4.1.7.3 Interaction effects of fertilizer and polluted soils on the metal accumulation in boro and T. Aman rice

Pertaining to the interaction effects between polluted soils and fertilizer treatments on heavy metal accumulations, significant variation was noted in both boro and T. Aman rice grains (Table 5). The higher levels of Cd concentrations were observed in the grains of *Boro* rice compared to T. Aman rice. In the grains of boro rice, the highest Cd concentration (0.33 ppm) was measured in T_1S_3 and the lowest (0.06 ppm) in T_0S_1 treatment combination. The Zn concentration, in boro rice (40.57 ppm) was found maximum in T_1S_3 treatment combination, whereas the minimum value (13.74 ppm) was estimated in T_0S_1 treatment combination. The Cd concentration in T. Aman rice grain, was higher (0.07 ppm) in T_1S_3 and the lowest (0.03 ppm) in T_0S_1 treatment combination. The highest and the lowest concentrations of Zn (45.00 and 32.41 ppm) were revealed in T_1S_3 and T_0S_1 treatment combinations, respectively. The maximum concentration of Pb (0.14 ppm) was recorded in T_1S_3, which was statistically at part to T_2S_3 (0.13 ppm) treatment combination, and the minimum value (0.06 ppm) was found in both T_2S_1 and T_0S_1 treatment combinations.

Table 5. Effects of different gradients of polluted soils and fertilizer on cadmium, lead and zinc accumulation in boro and T. Aman rice grain

Treatments	**Boro rice**		**T. Aman rice**		
	Cd conc. (ppm)	**Zn conc. (ppm)**	**Cd conc. (ppm)**	**Zn conc. (ppm)**	**Pb conc. (ppm)**
Polluted soils type					
S_1	0.07c	15.90c	0.04c	33.22c	0.06c
S_2	0.10b	30.76b	0.05b	35.56b	0.10b
S_3	0.23a	38.05a	0.06a	41.45a	0.13a
SE	1.09×10^{-3}	0.099	7.24×10^{-4}	0.04	1.65×10^{-3}
Fertilizer gradients					
T_0	0.11c	23.82c	0.04c	35.55c	0.09c
T_1	0.17a	31.72a	0.05a	38.52a	0.10a
T_2	0.12b	29.17b	0.05b	36.16b	0.10b
SE	1.09×10^{-3}	0.099	7.24×10^{-4}	0.04	1.65×10^{-3}
Fertilizer gradients × Polluted soils type					
$S_1 \times T_0$	0.06h	13.74h	0.03g	32.41i	0.06f
$S_2 \times T_0$	0.08f	21.44e	0.05e	34.63f	0.09d
$S_3 \times T_0$	0.18c	36.28c	0.06c	39.60c	0.11b
$S_1 \times T_1$	0.07g	18.48f	0.04f	34.46g	0.07e
$S_2 \times T_1$	0.11d	36.12c	0.05d	36.09d	0.10c
$S_3 \times T_1$	0.33a	40.57a	0.07a	45.00a	0.14a
$S_1 \times T_2$	0.07g	15.48g	0.04f	32.79h	0.06f
$S_2 \times T_2$	0.10e	34.72d	0.05e	35.95e	0.10cd
$S_3 \times T_2$	0.19b	37.30b	0.06b	39.74b	0.13a
SE	1.88×10^{-3}	0.172	1.25×10^{-3}	0.06	2.86×10^{-3}
CV (%)	1.74	0.74	3.18	0.22	3.66

In a column, figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT. S_1 –Non-polluted Soil, S_2 –Polluted Soil 1, S_3 –Polluted Soil 2, T_0 –Control, T_1 – $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$(100%RDCF), T_2 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$(50% RDCF) + 6-ton Cowdung/ha.

4.1.8 Effect of polluted soils and fertilizer on the chemical properties of soil

The polluted soils and fertilizer gradients exerted significant effect on different properties of soils, like soil-pH, OM, K, N, P, S, Zn, Cu, Mn, Fe, Ca, Mg, Cd, Pb, Cr and Ni as mentioned in Table 6.

4.1.8.1 Single effect of polluted soils on the chemical properties of soil

Maximum pH (5.82), OM (2.20%), K (0.23 meq/100g), N (0.13%), P (36.75 ppm), S (30.89 ppm) and Cu (53.56 ppm) were recorded in the soils of S_1 treated pots when the main effect of polluted soils was concerned. Whereas, the minimum values of pH (5.65), OM (1.76%), K (0.18 meq/100g), N (0.10%), P (25.90 ppm), S (25.27 ppm) and Cu (34.80 ppm) were recorded in S_3 soils. However, maximum values of Mn (79.47 ppm), Fe (1449.40 ppm), Ca (56.07 ppm) and Mg (8.92 ppm) were found in S_1 treated pots, and the minimum corresponding values of 65.09, 1182.80, 52.04 and 7.19 ppm, respectively, were observed in S_3 treated pots. Moreover, the highest values of Zn, Cd, Pb, Cr and Ni (19.55, 0.30, 32.85, 66.20 and 15.29 ppm, respectively) were nited in the soils of S_3 treated pots, whereas the lowest values (15.81, 0.25, 21.96, 46.01 and 12.42 ppm, respectively) were found in S_1 treated pots. Higher levels of pollutants (Cd, Pd, Cr and Ni) were observed in the S_2 and S_3 soils due to industrial pollution.

4.1.8.2 Effect of fertilizer on the chemical properties of soils

When the main effects of different fertilizer levels were concerned the highest pH (5.82), OM (2.03%), K (0.22 meq/100g), P (33.39 ppm), S (29.28 ppm), and Cu (47.19 ppm) were observed the highest in T_2 treated pots, whereas the corresponding lowest values of these parameters were noticed in T_0 treated pots. However, the highest N (0.12%) was recorded in T_2 treatment and the lowest value (0.11%) was found in both T_0 and T_1 treated pots. The higher Mn (76.91 ppm), Fe (1357.30 ppm), Ca (54.90 ppm), Mg (8.30 ppm) concentrations were found maximum in T_2 treated pots, and the minimum values (68.22, 1222.30, 53.13 and 7.79 ppm, respectively) were observed in

T_0 treated pots. However, the highest value of Cd (0.28 ppm) was observed in the soils of both T_1 and T_2 treated pots and the lowest one (0.26 ppm) was found in T_0 treatment. The highest and the lowest values of Zn (18.74 and 17.26 ppm), Pb (29.79 and 26.82 ppm), Cr (60.74 and 54.68 ppm) and Ni (14.75 and 13.07 ppm) were recorded in T_1 and T_0 treated pots, respectively. The higher levels of metals were found where inorganic fertilizers were applied. The application of manure may reduce the level of metals due to formation of metal-humus complex in the organic plus inorganic fertilizer treatments.

4.1.8.3 Interaction effect of fertilizer and polluted soils on the chemical properties of soils

Interaction effects between polluted soils and fertilizer gradients had pronounced influence on all parameters (Table 3.4) studied. The pH, OM (%), K (meq/100g), N (%), P, S, Zn, Cu, Mn, Fe, Ca, Mg, Cd, Pb, Cr and Ni concentrations of post experiment soils were significantly influenced by the interaction effects of fertilizer and soils. The highest and the lowest pH values (5.87 and 5.61) were seen in T_2S_1 and T_0S_3 treatments, respectively. Percentage OM was found the highest (2.42%) in T_2S_1, whereas the lowest value (1.72%) was recorded in T_0S_3 followed by T_1S_3 (1.75%) treatments. Maximum K (0.24 meq/100g) was found in T_2S_1 treatment, which was statistically similar to T_1S_1 (0.23 meq/100g) and the lowest (0.18 meq/100g) was observed in T_1S_3, which was statistically at par to T_0S_3 treatment. However, pertaining to N contents the highest value (0.14%) was recorded in T_1S_1 followed by T_2S_1 and the lowest (0.10%) was found in T_0S_3, T_1S_3 and T_2S_3 treatment, which were not significantly different from T_0S_2 and T_1S_2 (0.11%) treatments. The highest P content

(38.20 ppm) was estimated in T_2S_1 treatment, which was statistically similar T_1S_1 treatment (37.47 ppm) and the lowest value (24.28 ppm) was found in T_0S_3 treatment. The highest S content (33.33 ppm) was documented in T_2S_1 treatment, and the lowest value (24.35 ppm) was glittered in T_0S_3 treatment. Nevertheless, the higher concentration of Cu, Mn, Fe and Ca (55.98, 85.00, 1525.10, and 57.87 ppm, respectively) were obtained in T_2S_1 treatment and the lower values (33.71, 58.52, 1113.70 and 51.29 ppm, respectively) were recorded in T_0S_3. The maximum content of Mg (9.48 ppm) was seen in T_2S_1, while the minimum value (7.06 ppm) was recorded in T_0S_3 treatment. Meanwhile, the Cd content was found maximum (0.31 ppm) in T_1S_3 Which was followed by T_2S_3 (0.30 ppm) and the minimum value (0.22 ppm) was observed in T_0S_1 treatment. The augmented values of Zn, Pb, Cr and Ni (20.17, 37.04, 73.53 and 16.75 ppm, respectively) were recorded in T_1S_3 treatment, whilst the lower values (14.76, 21.15, 43.89 and 11.05 ppm, respectively) were estimated in T_0S_1 treatment. The higher levels of Zn, Pb, Cr, Cd concentrations were found in T_1S_3 (100% inorganic fertilizer + polluted soil-2) treatment, where inorganic fertilizer and polluted soils were used. The use of inorganic plus organic fertilizer application affected the polluted soils to remediate the levels of polluted metals from soils may be due to the formation of unavailable metal-humus complex in soils.

Table 6. Effects of different polluted soils and fertilizer treatments on soil properties

Treatment	**pH**	**OM (%)**	**K (meq/ 100g)**	**N (%)**	**P (ppm)**	**S (ppm)**	**Cu (ppm)**	**Mn (ppm)**	**Fe (ppm)**	**Ca (ppm)**	**Mg (ppm)**	**Zn (ppm)**	**Cd (ppm)**	**Pb (ppm)**	**Cr (ppm)**	**Ni (ppm)**
Polluted soils type																
S_1	5.82a	2.20a	0.23a	0.13a	36.75a	30.89a	53.56a	79.47a	1449.40a	56.07a	8.92a	15.81c	0.25c	21.96c	46.01c	12.42c
S_2	5.70b	1.84b	0.21b	0.11b	31.62b	27.42b	49.08b	73.30b	1266.40b	53.81b	7.88b	18.41b	0.27b	29.35b	59.00b	14.04b
S_3	5.65c	1.76c	0.18c	0.10c	25.90c	25.27c	34.80c	65.09c	1182.80c	52.04c	7.19c	19.55a	0.30a	32.85a	66.20a	15.29a
SE	0.01	0.02	4.47×10^{-3}	4.46×10^{-3}	0.35	0.22	0.32	0.31	0.54	0.30	0.10	0.24	1.95×10^{-3}	0.25	0.26	0.24
Fertilizer gradients																
T_0	5.69b	1.83c	0.20b	0.11a	29.30c	26.59c	44.34c	68.22c	1222.30c	53.13c	7.79b	17.26b	0.26b	26.82c	54.68c	13.07c
T_1	5.73a	1.93b	0.20b	0.12a	31.56b	27.70b	45.91b	72.73b	1319.00b	53.91b	7.91b	18.74a	0.28a	29.79a	60.74a	14.75a
T_2	5.75a	2.03a	0.22a	0.12a	33.39a	29.28a	47.19a	76.91a	1357.30a	54.90a	8.30a	17.77b	0.28a	27.55b	55.79b	13.93b
SE	0.01	0.02	4.47×10^{-3}	4.46×10^{-3}	0.35	0.22	0.32	0.31	0.54	0.30	0.10	0.24	1.95×10^{-3}	0.25	0.26	0.24
Fertilizer gradients × Polluted soils type																
$S_1\times T_0$	5.77b	1.96c	0.22b	0.13ab	34.57b	28.53c	51.97b	76.10c	1320.60c	54.51c	8.58b	14.76e	0.22e	21.15f	43.89h	11.05e
$S_2\times T_0$	5.69cd	1.82de	0.20d	0.11c	29.07d	26.89de	47.33d	70.05e	1232.50e	53.58cd	7.72c	18.20cd	0.27c	28.94d	58.23e	13.65cd
$S_3\times T_0$	5.61e	1.72f	0.18ef	0.10c	24.28f	24.35f	33.71f	58.52g	1113.70h	51.29f	7.06d	18.82bc	0.29b	30.37bc	61.93c	14.51bc
$S_1\times T_1$	5.83a	2.22b	0.23ab	0.14a	37.47a	30.80b	52.72b	77.31b	1502.50b	55.85b	8.70b	17.50d	0.26cd	22.47e	49.12f	13.18d
$S_2\times T_1$	5.69cd	1.83d	0.20cd	0.11c	31.62c	27.26d	49.74c	73.82d	1246.60d	53.69cd	7.84c	18.57c	0.27c	29.85cd	59.58d	14.33bc
$S_3\times T_1$	5.66d	1.75ef	0.18f	0.10c	25.60e	25.05f	35.29e	67.06f	1207.90g	52.18ef	7.18d	20.17a	0.31a	37.04a	73.53a	16.75a
$S_1\times T_2$	5.87a	2.42a	0.24a	0.14ab	38.20a	33.33a	55.98a	85.00a	1525.10a	57.87a	9.48a	15.17e	0.26d	22.25e	45.04g	13.03d
$S_2\times T_2$	5.72c	1.88d	0.22bc	0.12b	34.16b	28.12c	50.17c	76.03c	1320.00c	54.17c	8.08c	18.47c	0.27c	29.27d	59.18d	14.15bc
$S_3\times T_2$	5.68cd	1.80de	0.19de	0.10c	27.81d	26.39e	35.41e	69.70e	1226.70f	52.66de	7.34d	19.67ab	0.30a	31.14b	63.15b	14.62b
SE	0.02	0.04	7.74×10^{-3}	7.72×10^{-3}	0.61	0.37	0.55	0.54	0.94	0.51	0.18	0.42	3.38×10^{-3}	0.43	0.44	0.42
CV (%)	0.51	2.37	4.58	8.15	2.36	1.64	1.48	0.92	0.09	1.17	2.70	2.87	1.53	1.89	0.95	3.73

In a column, figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly. S_1 –Non-polluted Soil, S_2 –Polluted Soil 1, S_3 –Polluted Soil 2, T_0 –Control, T_1 – $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF), T_2 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6-ton cowdung/ha, OM – Organic matter.

4.2 Effect of irrigation and different sources of fertilizer and manure on the yield of rice and accumulation of metals in rice grown in arsenic contaminated soils of Narayanganj

Effect of fertilizer and irrigation on the yield attributes and yield of boro rice

4.2.1 Effect of fertilizer on the yield parameters and yield of boto rice

Variation was observed on the yield and its attributes of boro rice as influenced by irrigation water and different fertilizer treatments (Table 7). The main effect of different fertilizer gradients produced the highest rice plant height (77.51 cm) in T_4 treatment, which differed significantly with T_3 (76.83 cm) and T_2 (76.37 cm) treatments. Whereas the lowest plant height (71.92 cm) was measured in T_0 treated pot followed by T_1 (72.35 cm). The maximum total number of tillers hill^{-1} (33.47), panicle length (23.87 cm), and number of filled and unfilled grains panicle^{-1} (113.29 and 25.49, respectively) were observed in T_4 treatment, where 50% inorganic fertilizer and 5-ton compost ha^{-1} were applied. Whereas, the corresponding lowest values (27.15, 23.02 cm, 102.21 and 20.69, respectively) were recorded in plants grown in T_0 treated pots. The highest number of effective tillers hill^{-1} (28.00) was observed in T_4 treatment and the lowest value (21.17) was found in T_0 treatment followed by T_1 (21.83) treatment. Significant difference was not reflected regarding 1000 grain weight due to the main effect of different fertilizer treatments and numerically the highest and lowest values (19.80 and 19.04 g) of 1000-grain weight were recorded in T_4 and T_0 treated pots, respectively. Maximum straw (72.43 g pot^{-1}) and grain-yield (90.77 g pot^{-1}) were found in T_4 treated pot, and the minimum straw and grain yields were (44.63 and 57.11 g pot^{-1}, respectively) observed in T_0 treated pots.

4.2.2 Effect of irrigation on the yield parameters and yield of boro rice

The yield and yield parameters of rice differed significantly because of two irrigation treatments. The highest plant height (77.85 cm), total number of tillers hill^{-1} (33.53), number of effective tillers hill^{-1} (27.40), panicle length (23.92 cm), filled and unfilled grains panicle^{-1} (114.82 and 27.02), 1000 grain weight (19.84 g), straw yield (75.28 g pot^{-1}) and grain yield (94.03 g pot^{-1}) were observed in I_1 treatment, whereas the lowest plant height (72.14 cm), total number of tillers hill^{-1} (25.98), number of effective tillers hill^{-1} (21.00), panicle length (22.95 cm), filled and unfilled grains panicle^{-1} (101.51and 19.45), 1000 grain weight (19.01 g), straw yield (45.05 g pot^{-1}) and grain yield (55.98 g pot^{-1}) were noted in I_2 treatment.

4.2.3 Interaction effects of fertilizer and irrigation on the growth and yield of boro rice

The interaction effects of irrigation and fertilizer treatments noticeably influenced the morphological and yield-attributes of boro rice (Table 7). The maximum plant height of boro rice (79.00 cm) was observed in T_4I_1 treatment combination, followed by T_3I_1 (77.98 cm), T_2I_1 (77.66 cm), T_1I_1 (77.37 cm), T_0I_1 (77.25 cm) treatment. The minimum plant height (66.60 cm) was found in T_0I_2, followed by T_1I_2 (67.33 cm). The highest total number of effective tillers hill^{-1} (38.33) was counted in T_4I_1 and the lowest value (23.30) in T_0I_2 treatment. The number of effective tillers hill^{-1} was found maximum (33.00) in T_4I_1 treatment and the minimum (18.67) in T_0I_2 treatment. Nevertheless, the number of effective tillers hill^{-1} found in T_1I_2 (19.33) was not statistically differed. The maximum length of panicle (24.39 cm) was reported in T_4I_1 treatment followed by T_3I_1 (23.98 cm) and T_2I_1 (23.95 cm), whereas the minimum value (22.42 cm) was measured in T_0I_2

treatment. Number of filled grains panicle^{-1} (116.18) and straw yield (78.83 g pot^{-1}) were found the highest in T_4I_1 treatment followed by T_3I_1 (115.59 and 78.80 g pot^{-1}, respectively). Whereas, in T_0I_2 treatment, the lowest value was observed. The number of unfilled grains panicle^{-1} and grain yield (30.25 and 97.85 g pot^{-1}, respectively) were reported maximum in T_4I_1 treatment and minimum (17.89 and 24.23 g pot^{-1}, respectively) in T_0I_2. The maximum and minimum 1000-grain weights (20.17 and 18.56 g) were recorded in T_4I_1 and T_1I_2 treatments, respectively. The results indicated that T_4I_1 treatment performed better for obtaining better yield.

4.2.4 Effect of fertilizer on the yield parameters and yield of T. Aman rice

The effects of irrigation and fertilizer treatments significantly influenced the yields and yield- attributes of T. Aman rice (Table 8). Significant variations were noted due to the effects of different treatment in almost all the characters except weight of thousand grains. The highest plant height (126.53 cm) and total number of tillers hill^{-1} (30.67) were recorded in T_4 treatment. Whereas the lowest values of those parameters (115.13 cm and 23.67, respectively) were found in T_0 treatment. The maximum number of effective tillers hill^{-1} (25.00) was obtained in T_4 treatment and the minimum (18.17) was recorded in T_0 treatment. The highest length of the panicle (29.85 cm) was observed in T_4 treatment followed by T_3 (29.37 cm), whereas the lowest length (26.09 cm) was found in T_0 treatment. However, among the five treatments, the highest filled- and unfilled-grains panicle^{-1} (295.53 and 91.12), grain and straw-yields (40.23 g pot^{-1} and 57.95 g pot^{-1}, respectively) were observed in T_4 treatment. Whilst the lowest values of filled grains panicle^{-1} (231.38), unfilled-grains panicle^{-1} (54.38), grain yield (17.67 g pot^{-1}) and straw yield (36.52 g pot^{-1}) were recorded in T_0 treatment. The maximum and minimum values for thousand grain weights (20.00 and 19.67 g pot^{-1}) were recorded in T_4 and T_0 treatments, respectively.

Table 7. Yield and its attributes of boro rice as influenced by the main and interaction effects of irrigation methods and different fertilizer treatments

Treatments	Plant height (cm)	Total number of tillers hill^{-1} (No.)	Effective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1} (No.)	Un-filled grains panicle^{-1} (No.)	1000 grain wt. (g)	Straw yield (g pot^{-1})	Grain yield (g pot^{-1})
Fertilizer treatments									
T_0	71.92b	27.15d	21.17d	23.02c	102.21d	20.69e	19.04a	44.63e	57.11e
T_1	72.35b	28.67c	21.83d	23.24bc	106.24c	21.99d	19.11a	47.30d	60.38d
T_2	76.37a	28.83c	24.00c	23.40bc	109.36b	23.05c	19.49a	65.90c	79.59c
T_3	76.83a	30.67b	26.00b	23.65ab	109.74b	24.98b	19.75a	70.55b	87.18b
T_4	77.51a	33.47a	28.00a	23.87a	113.29a	25.49a	19.80a	72.43a	90.77a
SE	0.68	0.45	0.41	0.22	0.43	0.16	0.36	0.58	0.43
Irrigation treatments									
I_1	77.85a	33.53a	27.40a	23.92a	114.82a	27.02a	19.86a	75.28a	94.03a
I_2	72.14b	25.98b	21.00b	22.95b	101.51b	19.45b	19.01b	45.05b	55.98b
SE	0.43	0.28	0.26	0.14	0.27	0.10	0.23	0.37	0.28
Fertilizer × Irrigation treatments									
$T_0 \times I_1$	77.25abc	31.00c	23.67de	23.62bc	113.10c	23.48e	19.64a	70.60c	89.98d
$T_0 \times I_2$	66.60e	23.30f	18.67g	22.42e	91.32g	17.89h	18.44b	18.67h	24.23i
$T_1 \times I_1$	77.37abc	31.67c	24.33d	23.67bc	114.02bc	25.18d	19.66a	73.23b	92.78c
$T_1 \times I_2$	67.33e	25.67e	19.33g	22.80de	98.45f	18.80g	18.56b	21.37g	27.98h
$T_2 \times I_1$	77.66abc	32.00c	26.67c	23.95abc	115.21ab	26.97c	19.72a	74.93b	93.77c
$T_2 \times I_2$	75.08d	25.67e	21.33f	22.86de	103.50e	19.12g	19.25ab	56.87f	65.41g
$T_3 \times I_1$	77.98ab	34.67b	29.33b	23.98ab	115.59a	29.23b	20.13a	78.80a	95.77b
$T_3 \times I_2$	75.67cd	26.67e	22.67e	23.32cd	103.88e	20.72f	19.36ab	62.30e	78.58f
$T_4 \times I_1$	79.00a	38.33a	33.00a	24.39a	116.18a	30.25a	20.17a	78.83a	97.85a
$T_4 \times I_2$	76.01bcd	28.60d	23.00e	23.34bcd	110.40d	20.73f	19.43ab	66.03d	83.70e
SE	0.97	0.63	0.58	0.31	0.60	0.22	0.51	0.82	0.61
CV (%)	1.58	2.60	2.94	1.61	0.68	1.18	3.24	1.67	1.00

In a column, figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per LSD. I_1 – Traditional irrigation i.e. continuous flooding (2-3 cm water), I_2 –Alternate wetting drying, T_0 –Control, T_1 – $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF), T_2 – $N_{150}P_{60}K_{60}S_{20}Zn_{3.0}$, T_3 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6 ton Cowdung/ha T_4 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF + 5 ton compost/ha).

4.2.5 Effect of irrigation on the yield attributes and yield of T. Aman rice

Both types of irrigation methods exerted significant effects on all the yield-attributes, except thousand grain weight (Table 8). However, the highest and the lowest plant heights (126.71 and 114.87 cm) were recorded in I_1 and I_2 treatments, respectively. The maximum total number of effective tillers (30.65), effective tillers hill^{-1} (24.20), panicle length (29.74 cm), number of filled (288.94) and unfilled grains (91.49) per panicle, straw and grain-yield (57.85 and 40.80 g pot^{-1}) were recorded in I_1 treatment, whereas the lowest values of those respective parameters (23.00, 18.00, 26.69 cm, 233.36, 48.57, 31.46 g pot^{-1} and 14.87 g pot^{-1}, respectively) were noticed in I_2 treatment. The higher and lower weight of thousand grains (20.07 and 19.60 g) were noticed in I_1 and I_2 irrigation treatments, respectively. The results indicated that the continuous flooding irrigation increased the growth and yield of T. Aman rice.

4.2.6 Interaction effects of fertilizer and irrigation yield attributes and yield of T. Aman rice

Interaction effects between irrigation methods and fertilizer regimes remarkably influenced the plant morphological and yield-attributes, except the weight of thousand grains (Table 8). Plant height was found the highest (128.93 cm) in T_4I_1, whereas the lowest (106.00 cm) was recorded in T_0I_2 treatment. The maximum total number of effective tillers hill^{-1} (34.33) was observed in T_4I_1 treatment, whereas the minimum (19.33) was found in T_0I_2 treatment. The highest number of effective tillers hill^{-1} (30.00) was observed in T_4I_1, and the lowest number of effective tillers hill^{-1} (15.67) was found in T_0I_2 treatment, which was statistically similar to T_1I_2 (16.33) treatment. The highest panicle length (30.90 cm) was observed in T_4I_1 treatment followed by T_3I_1 (29.93 cm), whereas the lowest value (23.05 cm) was observed in T_0I_2 treatment combination. The highest filled- and unfilled-grains panicle^{-1} (324.87 and 108.57, respectively) were recorded in T_4I_1 treatment and the lowest values for these two parameters (195.60 and 33.70, respectively) were found in T_0I_2 treatment. However, numerically the higher and lower weight of thousand grains (20.33 and 19.33 g) were observed in T_4I_1 and T_0I_2 treatments, respectively. The maximum straw (78.27 g pot^{-1}) and grain-yield (55.07 g pot^{-1}) were obtained in T_4I_1 treatment, and the minimum straw and grain-yields (23.60 and 5.60g pot^{-1}) were found in T_0I_2 treatment.

4.2.7 Effect of fertilizer treatment on the metal accumulation in rice grain

The concentration of Cd, As, and Zn in boro rice grains and Cd, Zn, and Pb in T. Aman rice grains varied significantly with the variations of irrigation and fertilizer treatments (Table 9). The higher levels of Cd concentrations were noticed in T. Aman rice grain in comparison to boro rice grain. In boro rice grains, the highest and lowest concentration of Cd (0.06 and 0.04 ppm) were recorded in T_2 and T_0 treatments, respectively. However, the highest concentration of As (0.24 ppm) in boro rice grain was noted in T_2 treatment, whereas, the lowest (0.20 ppm) was noted in T_0 treatment. This result indicated that application of higher levels of phosphatic fertilizer increased the As accumulation. The highest and the lowest (31.87 and 21.73 ppm) Zn concentrations of boro rice grains were recorded in T_2 and T_0 treatments, respectively. The utmost concentrations of Cd (0.21 ppm) and Pb (0.107 ppm) of T. Aman rice grains were estimated in T_2 treated pots, whereas the lowest Cd and Pb (0.16 and 0.042 ppm, respectively) concentrations were noted in T_0 treatment. The highest and lowest Zn concentrations in T. Aman rice grains, (28.11 and 23.38 ppm) were recorded in T_2 and T_0 treated pots, respectively. The higher levels of Cd and Pb were accumulated in T. Aman rice grain with T_2 treatment where inorganic fertilizer and higher levels of phosphate fertilizer were used.

Table 8. Yield and its attributes of T. Aman rice as influenced by the main and interaction effects of irrigation and different fertilizer treatments

Treatments	**Plant height (cm)**	**Total of tillers hill^{-1} (No.)**	**Effective tillers hill^{-1} (No.)**	**Panicle length (cm)**	**Filled grains panicle^{-1} (No.)**	**Un-filled grains panicle^{-1} (No.)**	**1000 grain wt. (g)**	**Straw yield (g pot^{-1})**	**Grain yield (g pot^{-1})**
Fertilizer gradients									
T_0	115.13d	23.67e	18.17d	26.09d	231.38e	54.38e	19.67a	36.52e	17.67e
T_1	116.53c	25.13d	18.83d	27.22c	235.70d	60.60d	19.83a	40.67d	19.98d
T_2	122.78b	26.67c	20.50c	28.55b	263.73c	65.50c	19.83a	42.58c	28.28c
T_3	122.98b	28.00b	23.00b	29.37a	279.40b	78.53b	19.83a	45.55b	33.00b
T_4	126.53a	30.67a	25.00a	29.85a	295.53a	91.12a	20.00a	57.95a	40.23a
SE	0.21	0.40	0.55	0.35	0.60	0.64	0.56	0.46	0.49
Irrigation methods									
I_1	126.71a	30.65a	24.20a	29.74a	288.94a	91.49a	20.07a	57.85a	40.80a
I_2	114.87b	23.00b	18.00b	26.69b	233.36b	48.57b	19.60a	31.46b	14.87b
SE	0.13	0.25	0.35	0.22	0.38	0.41	0.35	0.29	0.31
Fertilizer gradients × Irrigation methods									
$T_0 \times I_1$	124.27d	28.00cd	20.67de	29.13bc	267.17e	75.07d	20.00a	49.43d	29.73e
$T_0 \times I_2$	106.00g	19.33g	15.67g	23.05f	195.60h	33.70g	19.33a	23.60i	5.60j
$T_1 \times I_1$	126.27c	28.60c	21.33cd	29.13bc	270.80d	84.80c	20.00a	52.73c	31.93d
$T_1 \times I_2$	106.80f	21.67f	16.33g	25.30e	200.60g	36.40f	19.67a	28.60h	8.03i
$T_2 \times I_1$	126.99b	30.67b	22.67c	29.60bc	275.40c	94.07b	20.00a	53.23c	40.33c
$T_2 \times I_2$	118.57e	22.67f	18.33f	27.50d	252.07f	36.93f	19.67a	31.93g	16.23h
$T_3 \times I_1$	127.10b	31.67b	26.33b	29.93ab	306.47b	94.93b	20.00a	55.57b	46.93b
$T_3 \times I_2$	118.87e	24.33e	19.67ef	28.80c	252.33f	62.13e	19.67a	35.53f	19.07g
$T_4 \times I_1$	128.93a	34.33a	30.00a	30.90a	324.87a	108.57a	20.33a	78.27a	55.07a
$T_4 \times I_2$	124.13d	27.00d	20.00de	28.80c	266.20e	73.67d	19.67a	37.63e	25.40f
SE	0.30	0.57	0.78	0.49	0.85	0.91	0.79	0.65	0.69
CV (%)	0.30	2.60	4.51	2.15	0.40	1.59	4.85	1.79	3.03

In a column, figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per LSD. I_1 – Traditional irrigation i.e. continuous flooding (2-3 cm water), I_2 –Alternate wetting drying, T_0 –Control, T_1 – $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100%RDCF), T_2 – $N_{150}P_{60}K_{60}S_{20}Zn_{3.0}$, T_3 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50%RDCF) + 6 ton Cowdung/ha T_4 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50%RDCF + 5 ton Compost/ha).

4.2.8 Effect of irrigation on the accumulation of metals in rice grain

The effect of irrigation methods on heavy metal accumulation in boro rice grains showed that the maximum accumulation of Cd (0.07 ppm), As (0.25 ppm) and Zn (31.41 ppm) occurred in I_2 treatment, whereas the minimum values (0.04, 0.19 and 22.28 ppm, respectively) were recorded in I_1 treatment. In T. Aman rice, the highest concentrations of accumulated Cd and Pb (0.22 and 0.107 ppm, respectively) were obtained in I_2 treatment, whereas the lowest values of those heavy metals (0.15 and 0.034 ppm, respectively) were found in I_1 treatment. In case of Zn, the utmost and the abated values (29.69 and 22.54 ppm) were obtained in I_2 and I_1 treatments, respectively.

4.2.9 Interaction effect of irrigation and fertilizer on the metal accumulation in rice

Pertaining to the interaction effects between irrigation types and fertilizer treatments on heavy metal accumulations in rice grains, significant variation was observed for both boro and T. Aman rice. The higher levels of Cd concentrations were noted in T. Aman rice grain in comparison to boro rice grain. In grains of boro rice, the highest Cd concentration (0.08 ppm) was recorded in both T_1I_2 and T_2I_2 treatment, whereas the lowest value (0.03 ppm) was estimated in T_0I_1 treatment. In response to Cd accumulation in T. Aman grains, the highest Cd concentration (0.26 ppm) was documented in T_2I_2 and the lowest value (0.14 ppm) was recorded in several treatments, including T_0I_1, T_3I_1 and T_4I_1. Higher Cd accumulation was observed in the treatments, where inorganic fertilizer and lower levels of irrigation (I_2) water were applied. Moreover, in response to As concentration in boro rice, the utmost value (0.27 ppm) was observed in T_2I_2 treatment, whereas the lowest value (0.18 ppm) was recorded in T_0I_1 treatment. Lower levels of irrigation (alternate wetting and drying) decreased As accumulation. The higher levels of Zn concentration were observed in boro rice. The highest and the lowest Zn accumulation (38.50 and 17.98 ppm) in boro rice grains were obtained in T_2I_2 and T_0I_1 treatment combinations, respectively. However, the highest accumulated Zn concentration (30.77 ppm) in T. Aman rice was recorded in T_2I_2, which was statistically similar to T_1I_2 (30.74 ppm) treatment combination. Whereas the lowest accumulation of Zn (19.14 ppm) was observed in T_0I_1 treatment combination. Higher Zn accumulation was observed in the treatment combinations, where inorganic fertilizer and lower levels of irrigation water were applied. Moreover, the maximum concentration of Pb (0.142 ppm) was recorded in T_2I_2 and the minimum (0.002 ppm) was estimated in T_0I_1 treatment combination. Higher Pb accumulation was found in the treatment combinations, where inorganic fertilizer and lower levels of irrigation water were applied.

4.2.10 Effect of irrigation and fertilizer on the chemical properties of soil

4.2.10.1 Effect of fertilizer on the chemical properties of soil

The effects of irrigation types and fertilizer gradients on the properties of soils like soil-pH, OM, K, N, P and S were documented in Table 9. The highest soil pH (6.27), percentage of OM (1.71%), P (55.73 ppm) and S (8.07 ppm) were recorded in T_4 treatment due to the main effect of fertilizer treatments. Whereas, the lowest values of those parameters including, soil pH (6.16), OM (1.39%), P (46.33 ppm) and S (4.80 ppm) were recorded in T_0 treatment. However, maximum K (0.12 meq 100g^{-1}) was found in T_4 treatment, which was statistically similar to all other treatments except the lowest (0.10 meq 100g^{-1}) found in T_0 treatment. The highest N (0.10%) was recorded in T_4 treatment followed by both T_3 and T_2 (0.09%) treated pots. Whereas the lowest value (0.08%) was documented in both T_0 and T_1 treatments. The application of 50% inorganic fertilizer plus 5 ton compost ha^{-1} or 6 ton cowdung ha^{-1} increased the nutrient in soil.

Table 9. Effects of irrigation and different fertilizers treatments on cadmium, arsenic, lead and zinc accumulation in boro and T. Aman rice grain

Treatments	**Boro rice**			**T. Aman rice**		
	Cd conc. (ppm)	**As conc. (ppm)**	**Zn conc. (ppm)**	**Cd conc. (ppm)**	**Zn conc. (ppm)**	**Pb conc. (ppm)**
Fertilizer gradients						
T_0	0.04d	0.20e	21.73e	0.16e	23.38e	0.042e
T_1	0.06b	0.23b	29.99b	0.20b	27.52b	0.091b
T_2	0.06a	0.24a	31.87a	0.21a	28.11a	0.107a
T_3	0.05c	0.23c	27.88c	0.18c	26.05c	0.065c
T_4	0.05c	0.21d	22.75d	0.17d	25.53d	0.048d
SE	1.46×10^{-3}	1.40×10^{-3}	0.05	1.63×10^{-3}	0.04	1.63×10^{-3}
Irrigation methods						
I_1	0.04b	0.19b	22.28b	0.15b	22.54b	0.034b
I_2	0.07a	0.25a	31.41a	0.22a	29.69a	0.107a
SE	9.26×10^{-4}	8.83×10^{-4}	0.03	1.03×10^{-3}	0.03	1.03×10^{-3}
Fertilizer gradients ×Irrigation methods						
$T_0\times I_1$	0.03e	0.18h	17.98i	0.14g	19.14i	0.002j
$T_0\times I_2$	0.05c	0.23d	25.48e	0.19e	27.61d	0.082e
$T_1\times I_1$	0.04d	0.20f	25.09f	0.16f	24.29f	0.065g
$T_1\times I_2$	0.08a	0.26b	34.88b	0.24b	30.74a	0.116b
$T_2\times I_1$	0.05c	0.20e	25.23f	0.16f	25.45e	0.071f
$T_2\times I_2$	0.08a	0.27a	38.50a	0.26a	30.77a	0.142a
$T_3\times I_1$	0.04de	0.19g	23.38g	0.14g	22.36g	0.023h
$T_3\times I_2$	0.06b	0.26b	32.38c	0.23c	29.73b	0.106c
$T_4\times I_1$	0.04de	0.19g	19.71h	0.14g	21.47h	0.008i
$T_4\times I_2$	0.06b	0.24c	25.79d	0.20d	29.59c	0.088d
SE	2.07×10^{-3}	1.97×10^{-3}	0.07	2.31×10^{-3}	0.06	2.30×10^{-3}
CV (%)	4.79	1.09	0.33	1.52	0.28	4.00

In a column, figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per LSD. I_1 – Traditional irrigation i.e. continuous flooding (2-3 cm water), I_2 –Alternate wetting drying, T_0 –Control, T_1 – $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100%RDCF), T_2 – $N_{150}P_{60}K_{60}S_{20}Zn_{3.0}$, T_3 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50%RDCF) + 6 ton Cowdung/ha T_4 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50%RDCF + 5 ton Compost/ha).

4.2.10.2 Effect of irrigation on the chemical properties of soil

In response to two types of irrigation, higher soil pH (6.28), OM (1.63%), K (0.12 meq $100g^{-1}$), N (0.10%), P (58.02 ppm) and S (8.00 ppm) were recorded in I_1 treatment, whereas the lower values of those respective parameters (6.13, 1.36%, 0.10 meq $100g^{-1}$, 0.08%, 46.19 ppm, and 5.30 ppm, respectively) were noted in I_2 treatment. The increasing levels of organic matter and nutrient in continuous flooded condition might be due to slower rate of mineralization of nutrient.

4.2.10.3 Interaction effect of fertilizer and irrigation on the chemical properties of soil

Interaction effects between irrigation types and fertilizer gradients significantly influenced the soil properties. The highest and lowest (6.33 and 6.06) soil pH were recorded in T_4I_1 and T_0I_2 treatments, respectively. The highest OM percentage (2.00%) was observed in T_4I_1, whereas the lowest value (1.31%) was recorded in both T_0I_2 and T_1I_2 treatments. The application of 50% inorganic fertilizer plus 5-ton compost ha^{-1} or 6-ton cowdung ha^{-1} increased the level of OM. The maximum K (0.13 meq/100g) was found in T_4I_1 treatment combination, which was statistically similar to T_3I_1 treatment. In contrast, the minimum value (0.09 meq $100g^{-1}$) of that parameter was recorded in T_0I_2, which was statistically similar to T_1I_2 treatment. Similarly, the highest N (0.12%) was recorded in T_4I_1 treatment, which was statistically similar to T_3I_1 (0.10%) treatment and the lowest (0.08%) was observed in T_0I_2, T_1I_2, T_2I_2, T_3I_2 and T_4I_2 treatments followed by all the other treatment (0.09%). The highest P (63.33 ppm) was observed in T_4I_1 treatment and the lowest (43.96

ppm) was found in T_0I_2, which was statistically similar to T_1I_2 (44.18 ppm). The maximum and minimum values of S (9.54 and 3.00 ppm) were obtained in T_4I_1 and T_0I_2 treatments, respectively. The results indicate that the soil nutrient levels increased more with the application of T_4I_1 treatment (Table 10).

Table 10. Effects of irrigation and different fertilizers treatments on soil properties

Treatments	**pH**	**OM (%)**	**K** (meq/100g)	**N (%)**	**P** (ppm)	**S** (ppm)
Fertilizer gradients						
T_0	6.16d	1.39d	0.10b	0.08b	46.33d	4.80e
T_1	6.18c	1.40d	0.10ab	0.08b	51.05c	5.97d
T_2	6.20c	1.43c	0.11ab	0.09ab	53.55b	6.91c
T_3	6.21b	1.54b	0.11ab	0.09ab	53.88b	7.51b
T_4	6.27a	1.71a	0.12a	0.10a	55.73a	8.07a
SE	6.95×10^{-3}	8.04×10^{-3}	6.57×10^{-3}	8.01×10^{-3}	0.28	0.07
Irrigation methods						
I_1	6.28a	1.63a	0.12a	0.10a	58.02a	8.00a
I_2	6.13b	1.36b	0.10b	0.08b	46.19b	5.30b
SE	4.39×10^{-3}	5.09×10^{-3}	4.16×10^{-3}	5.06×10^{-3}	0.18	0.04
Fertilizer gradients ×Irrigation methods						
$T_0 \times I_1$	6.26b	1.47d	0.11bcde	0.09b	48.69d	6.60e
$T_0 \times I_2$	6.06g	1.31f	0.09f	0.08b	43.96g	3.00i
$T_1 \times I_1$	6.27b	1.49d	0.11abcd	0.09b	57.93c	6.83d
$T_1 \times I_2$	6.10f	1.31f	0.09ef	0.08b	44.18g	5.11h
$T_2 \times I_1$	6.27b	1.52c	0.12abc	0.09b	59.99b	8.13c
$T_2 \times I_2$	6.12e	1.33f	0.10def	0.08b	47.11f	5.69g
$T_3 \times I_1$	6.27b	1.67b	0.13ab	0.10ab	60.18b	8.93b
$T_3 \times I_2$	6.15d	1.41e	0.10def	0.08b	47.59ef	6.10f
$T_4 \times I_1$	6.33a	2.00a	0.13a	0.12a	63.33a	9.54a
$T_4 \times I_2$	6.20c	1.42e	0.10cdef	0.08b	48.13de	6.59e
SE	9.83×10^{-3}	0.01	9.3×10^{-3}	0.01	0.39	0.10
CV (%)	0.19	0.93	10.61	15.88	0.93	1.80

In a column, figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per LSD. I_1 – Traditional irrigation i.e. continuous flooding (2-3 cm water), I_2 –Alternate wetting drying, T_0 –Control, T_1 – $N_{150}P_{30}K_{60}S_{20}Zn_{3.0}$ (100% RDCF), T_2 – $N_{150}P_{60}K_{60}S_{20}Zn_{3.0}$, T_3 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF) + 6-ton Cowdung/ha T_4 – $N_{75}P_{15}K_{30}S_{10}Zn_{1.5}$ (50% RDCF + 5-ton compost/ha),
OM – Organic matter.

4.3 Assessment of toxic metals in wastewater on the livelihood and food security of the local people around the industrial area

4.3.1 Socioeconomic conditions of the respondents

Age of the respondents: According to the age, respondents were categorized into three groups such as young- (below 35), middle- (35-50) and old- (above 50) aged. In the studied area, 52% of the respondents belonged to the middle-aged group 30% were under old-aged, and only 18% were young-aged (Table 11).

Table 11. Distribution of the respondents according to their age

Categories	**Respondents**	
	Frequency	**Percent (%)**
Young age (<35 years)	9	18
Middle age (35-50 years)	26	52
Old age (>50 years)	15	30
Total	50	100

Literacy level: Information on educational status in terms of literacy levels were classified into five categories as presented in Table 12. Unfortunately, majority of the respondents were intrinsic in no education (36%) and can sign only (32%) groups, although 22% of the respondents were found to complete their primary education. Regrettably, only 6 and 4% of the respondents completed their secondary education, and S.S.C and above, respectively (Table 12).

Table 12. Distribution of the respondents according to their literacy level

Categories	Respondents	
	Frequency	Percent (%)
Illiterate / No education	18	36
Can sign only	16	32
Primary education (up to class 5)	11	22
Secondary education (class 6 to 10)	3	6
S.S.C. and above	2	4
Total	50	100

Family size: Based on the number of family members, family size was grouped into three categories, including small (up to 4 members), medium (5-8 members) and large (above 8 members). Among 50 respondent's family, 32 families (64%) belonged to medium-sized, while 10 (20%) and 8 (16%) families were under small- and large-family-sized, respectively (Table 13).

Table 13. Distribution of the respondents according to their family size

Categories	Respondents		Mean	SD
	Frequency	Percent (%)		
Small (up to 4 members)	10	20	5.8	2.1
Medium (5-8 members)	32	64		
Large (above 8 members)	8	16		
Total	50	100		

Secondary occupation: Besides farming practices as a primary occupation, peoples were involved in a number of secondary occupations, like driving, fishing, business and labor. It is worth noting that the diversification of profession other than key occupation plays a vital role in augmenting people's income. However, majority of respondents engaged in driving (36%) and fishing (32%) as a secondary source of income, while 22% of the respondents doing business and only 10% worked as a day labor (Table 14).

Table 14. Distribution of the respondents according to secondary occupation

Categories	Respondents	
	Frequency	**Percent (%)**
Driving	18	36
Fishing	16	32
Business	11	22
Labour	5	10
Total	50	100

Farm size: According to the size of the farm, the respondents were classified into landless (up to 0.2 ha), marginal (0.20-0.60 ha), small (0.60-1.00 ha), medium (1.00-3.00 ha) and large (above 3.00 ha) groups. Nonetheless, most of the farmers were inherent in small (36%) and marginal (32%) categories, whereas only 10% were in medium category and 22% were landless. Regrettably, no respondents were found under large size farm category (Table 15).

Table 15. Distribution of the respondents according to their farm size

Categories	Respondents		Mean	SD
	Frequency	**Percent (%)**		
Landless farmer (up to 0.2 ha)	11	22	0.42	0.35
Marginal farmer (0.201 - 0.60 ha)	16	32		
Small farmer (0.601 - 1.00 ha)	18	36		
Medium farmer (1.001 - 3.00 ha)	5	10		
Large farmer (above 3.00 ha)	0	0		
Total	50	100		

Annual income: Based on annual income divergence, respondents were grouped into low, medium and high (Table 16). Nevertheless, majority of the respondents (38%) were in high category and earned above 2,00,00 BDT followed by medium (36%), and income ranged between 1,30,000 to 2,00,000 BDT. The rest of the respondents (26%) annual income was less than or equal Tk. 1,30,000 BDT and denoted as low category.

Table 16. Distribution of the respondents according to their annual income

Categories	Respondents		Mean	SD
	Frequency	Percent (%)		
Low (≤ Tk. 130,000)	13	26	214,300	141,726
Medium (Tk. 130,000 – 200,000)	18	36		
High (Above Tk. 200,000)	19	38		
Total	50	100		

4.3.2 Farmers' perception on impact of industrial effluent contamination in rice production

Several negative impacts of industrial effluent (IE) on rice field contamination were identified and farmer's perception regarding those were presented in Table 17. In response to the statement of IE-induced fertility reduction in rice field, 40% respondents strongly agreed, while majority (60%) of the respondents agreed. In case of industrial effluent (IE)-induced augmentation in rice production cost, 60% of the respondents agreed with the statement, while 30% strongly agreed with the statement and rest 10% were undecided. In response to IE-induced quality deterioration of rice, most of the respondents (70%) agreed with the statement, while rest of the respondents were distributed into strongly agreed (20%), undecided (6%) and disagreed (4%). In case of IE-induced declination in rice yield, 40% of the respondents concurred with the statement, while 20% of the respondents strongly agreed and undecided followed by disagree (14%) and strongly disagree (6%). IE-induced distortion of rice grain appearance lead to decline in grain price, although only 4% of the respondents strongly believe this. However, 40% of the respondents agreed to this problem and 40% had no problem, while the rest 16% of the respondents disagreed. Unfortunately, only 8 and 10% of the respondents strongly and moderately believed that the contaminated water from the IE as a source of irrigation was harmful, while 20% had no opinion. However, 12 and 50% of the respondents strongly and moderately considered that the use of contaminated water for irrigation was not harmful. Rapid industrialization led to water contamination was strongly and moderately agreed by 40 and 50% of the respondents, respectively, while 10% of the respondents did not provide any opinion. Situation becoming worsen day-by-day due to rapid industrialization, and this was strongly- and moderately-agreed by 50 and 40% of the respondents, respectively, whereas, 10% of the respondents did not provide any viewpoint. Due to exploration of contaminated area, peoples are not curious in rice production, like in the recent past and this was firmly- and reasonably-agreed by 26 and 40% of the respondents, respectively. On the other hand, 20% of the respondents were doubtful, and 10 and 4% of the respondents were moderately- and strongly-denied that reason, respectively. Paucity of information and awareness regarding IE-induced contamination in rice field was strongly- and moderately-affirmed by 20 and 50% of the respondents, respectively, whilst 20, 8 and 2% of the respondents were in vague, and reasonably and strictly contradict to this statement, respectively.

Table 17. Distribution of the respondents according to their perception on impact of industrial effluent contamination in rice production

Statements	Respondents' perception (% respondents)				
	***SA**	**A**	**UD**	**DA**	**SDA**
Industrial effluent reduced fertility of rice field	40	60	0	0	0
Industrial effluent contamination increases cost of rice production	30	60	10	0	0
Rice quality declined than before as a result of effluent	20	70	6	4	0
Yield of rice reduced due to effluent contamination	20	40	20	14	6
Price of rice declined because of decreased face value	4	40	40	16	0
Using effluent contaminated water as irrigation is not much harmful	12	50	20	10	8
Water contamination increased after establishment of industries	40	50	10	0	0
Situation is becoming unfavorable day-by-day	50	40	10	0	0
As contamination increased people aren't interested in rice production like before	26	40	20	10	4
Information and awareness about impact of effluent contamination is inadequate	20	50	20	8	2

*SA=strongly agree, A= Agree, UD= Undecided, DA= Disagree, SDA= strongly disagree.

4.3.3 Distribution of the respondents according to their perception on impact of industrial effluent contamination in rice production

Based on the respondent's consciousness regarding IE-induced contamination in rice field, three groups namely unfavorable, favorable and highly favorable (Table 18)**.** Amusingly, 16 and 60% of the respondents had higher and moderate favorable perception on rice production impacted by IE, while 24% of the respondents had unfavorable concept.

Table 18. Distribution of the respondents according to their perception on impact of industrial effluent contamination in rice production

Categories	Respondents		Mean	SD
	Number	Percent (%)		
Unfavorable perception (below 35 score)	12	24	38.7	6.32
Favorable perception (35-40 score)	30	60		
Highly favorable perception (above 40)	8	16		
Total	50	100		

4.3.4 Farmers' perception on change in color and odor of soil before and after the establishment of industries

It is worth mentioning that the color and odor of the soils are becoming gradually deteriorate after establishment of the industry. However, farmers provided opinions in respect of the transformation of soil color and odor after industrialization, which were classified into four groups, namely very good, good, bad and very bad. Importantly, 90 and 10% of the respondents in each case opined that the soil color and odor were very good and good, respectively, before initiation of any industry (Table 19). However, after inauguration of industry, percent of respondent's opinions regarding soil color dipped down and reached 60 and 40% in respect of very good and good, respectively, whereas for odor it was reached to 70, 24, and 6% for very good, good and bad category, respectively.

Table 19. Distribution of the respondents according to their response on color and odor of soil before and after the establishment of industries

Categories	**Color**				**Odor**			
	Before		**After**		**Before**		**After**	
	F*	**P* (%)**	**F**	**P (%)**	**F**	**P (%)**	**F**	**P (%)**
Very good	45	90	30	60	45	90	35	70
Good	5	10	20	40	5	10	12	24
Bad	-	-	-	-	-	-	3	6
Very bad	-	-	-	-	-	-	-	-

F* = Frequency, P* = Percentage.

4.3.5 Farmers' Perception on color and odor of surface water before and after the establishment of industries

Before commercial industrialization, people used surface water for drinking and cooking purpose in most parts of Bangladesh. However, rapid industrialization especially initiation of tannery, medicine and garments industry concomitantly deteriorated the water quality through its disposal. Four indicators, such as very good, good, bad and very bad were used to evaluate the people's perception on water quality in terms of color and odor (Table 20). Nonetheless, 84 and 88% of the respondents', respectively, opined that the color and odor of the surface water as a drinking source was very good at pre-establishment of the industry, while 16 and 12% of the respondents said good. Nowadays, after inauguration of industry, peoples were not willing to use surface water for drinking purpose, which become evident by their negative opinion as bad and very bad in terms of color (64 and 36%, respectively) and odor (52 and 48%, respectively). Nonetheless, in response to the opinion of using surface water as cooking purpose before arrival of industry and 58 and 42% of the respondents opined that the color, and 66 and 34% of the respondents said that the odor was very good and good, respectively. In contrast, the recent perception had dramatically changed to bad (74 and 78%) and very bad (26 and 22%) in terms of cooking watercolor and odor indicators, respectively.

It is also worth mentioning that most of the peoples in Bangladesh previously used surface water for their domestic purposes like cloth- and dish-washing, as well as irrigated their field and even for bathing purpose. However, for the case of domestic usage, almost all of the respondents opined that the color and odor of the surface water was good (66 and 18%, respectively) and very good (34 and 82%, respectively) before industrial exploration, while now it had changed to bad (24 and 36%, respectively) and very bad (76 and 64%, respectively). Similar trend was noticed in the past in case of surface water usage for irrigation, and 76 and 24% of the respondents pronounced that the color, and 80 and 20% of the respondents opined that the odor was very good and good, respectively. Regrettably, after industrial activities, only 8 and 4% of the respondents alleged that the color and odor were good, while majority of the respondents said that the color and odor was altered to bad (88 and 80%, respectively) and very bad (4 and 60%, respectively). As parallel to the usage of surface water for domestic and irrigation purpose in the past, most of the respondents pronounced that the color and odor of surface water for bathing purpose was good (32 and 84%, respectively) and very good (68 and 16%, respectively). However, people's perception changed to bad (72 and 88%, respectively) and very bad (28 and 6%, respectively), although 6% of the respondents still said the odor was good.

Table 20. Distribution of the respondents according to their response on color and odor of surface water before and after the establishment of industries

Types of use	**Categories**	**Color**				**Odor**			
		Before		**After**		**Before**		**After**	
		F*	**P* (%)**	**F**	**P (%)**	**F**	**P (%)**	**F**	**P (%)**
Drinking	Very good	42	84	-	-	44	88	-	-
	Good	8	16	-	-	6	12	-	-
	Bad	-	-	32	64	-	-	26	52
	Very bad	-	-	18	36	-	-	24	48
Cooking	Very good	29	58	-	-	33	66	-	-
	Good	21	42	-	-	17	34	-	-
	Bad	-	-	37	74	-	-	39	78
	Very bad	-	-	13	26	-	-	11	22
Domestic activities	Very good	17	34	-	-	41	82	-	-
	Good	33	66	-	-	9	18	-	-
	Bad	-	-	12	24	-	-	18	36
	Very bad	-	-	38	76	-	-	32	64
Irrigation	Very good	38	76	-	-	40	80	-	-
	Good	12	24	4	8	10	20	2	4
	Bad	-	-	44	88	-	-	40	80
	Very bad	-	-	2	4	-	-	8	16
Bathing	Very good	16	32	-	-	42	84	-	-
	Good	34	68	-	-	8	16	3	6
	Bad	-	-	36	72	-	-	44	88
	Very bad	-	-	14	28	-	-	3	6

F* = Frequency, P* = Percentage

4.3.6 Farmers' perception on color and odor of groundwater before and after the establishment of industries

Before commercial industrialization, people in most part of the Bangladesh also used ground water by establishment of tube well and well for drinking and cooking purpose. However, current situation has changed drastically as the ground water are contaminated by different kinds of industrial disposal that are rich in toxic heavy metals, and often manifested by their altered color and odor. Nonetheless, 86 and 92% of the respondents', respectively opined that the color and odor of ground water as a drinking source was very good at pre-establishment of industry, while 14 and 8% of the respondents said that it was good. Nowadays, after inauguration of industry, people's perceptions changed in terms of color and odor indicators, which was manifested by their lower responds to very good (26 and 34%, respectively) and higher in good (68 and 54%, respectively), and even bad (6 and 12%, respectively) were observed in some cases. Similar opinion was also received for using ground water as cooking purpose before arrival of industry, 88 and 12% of the respondents opined that the color, and 50 and 50% of the respondents said that the odor was very good and good, respectively. Contrarily, the recent perception of the respondents had dramatically changed in terms of cooking watercolor, and only 28% of the respondents said that the color was very good, while 72% of the respondents pronounced it as good. Interestingly, people's perception on cooking water odor had changed positively and 60% of the respondents marked that as very good, while 32% opined as good and only 8% said as bad.

Likewise, surface water, peoples of Bangladesh especially in drought-prone areas previously used tube well water for their daily domestic activities, shallow tube well and/or low lift pump water to irrigate their crop field, and often for bathing purpose. However, for the case of domestic usage, almost all of the respondents opined that the color and odor of the ground water was very good (80 and 86%, respectively) and good (20 and 14%, respectively) before industrial exploration, while now it had changed, and only a limited portion of the respondents pronounced as very good (28 and 22%, respectively), although most of them opined as good (72 and 72%, respectively) and some spoken as bad (6% for water odor). Similar trend was noticed in the past in case of ground water usage for irrigation, and 86 and 14% of the respondents pronounced that the color and 80 and 20% of the respondents opined that the odor was very good and good, respectively. Regrettably, after industrial activities, 76 and 24% of the respondents alleged that the color was good and very good, respectively, while after establishment of industry only 14% of the respondents said that the odor was very good, although 86% opined as good. As parallel to the usage of surface water for domestic and irrigation purpose in the past, most of the respondents pronounced that the color and odor of ground water for bathing purpose was very good (82 and 78%, respectively) and good (18 and 22%, respectively). Interestingly, people's perception on bathing water odor had changed positively and 86% of the respondents marked that as very good, while 14% opined as good (Table 21). Whereas their perception regarding watercolor was changed to negatively as 24% very good and 76% good after industrial activities.

4.3.7 Farmers' perception on IE-induced impacts on rice yield

People's perception on IE-induced declination in rice yield was presented in Table 22. In case of *aus* rice, majority of the respondents (52%) surmised that the yield was moderately decreased followed by highly decreased (28%) and low extant of reduction (16%), while only 4% of the respondents thought no influential effect of IE on *aus* yield. However, for *aman* rice, 68% of the respondents presumed that low extant of yield reduction, while 22 and 10% pronounced as moderate and higher depreciation, respectively. Perilously, 68% of the respondents pretended that boro rice yield was highly reduced, while 22% spoke moderate deduction, and only 6% opined as low reduction.

Table 21. Distribution of the respondents according to their response on color and odor of groundwater before and after the establishment of industries

Types of use		**Color**				**Odor**			
	Categories	**Before**		**After**		**Before**		**After**	
		F*	**P* (%)**	**F**	**P (%)**	**F**	**P (%)**	**F**	**P (%)**
Drinking	Very good	43	86	13	26	46	92	17	34
	Good	7	14	34	68	4	8	27	54
	Bad	-	-	3	6	-	-	6	12
	Very bad	-	-			-	-	-	-
Cooking	Very good	44	88	14	28	25	50	30	60
	Good	6	12	36	72	25	50	16	32
	Bad	-	-	-	-	-	-	4	8
	Very bad	-	-	-	-	-	-	-	-
Domestic activities	Very good	40	80	14	28	43	86	11	22
	Good	10	20	36	72	7	14	36	72
	Bad	-	-	-	-	-	-	3	6
	Very bad	-	-	-	-	-	-	-	-
Irrigation	Very good	43	86	38	76	40	80	7	14
	Good	7	14	12	24	10	20	43	86
	Bad	-	-	-	-	-	-	-	-
	Very bad	-	-	-	-	-	-	-	-
Bathing	Very good	41	82	12	24	39	78	43	86
	Good	9	18	38	76	11	22	7	14
	Bad	-	-	-	-	-	-	-	-
	Very bad	-	-	-	-	-	-	-	-

F* = Frequency, P* = Percentage

Table 22. Distribution of the respondents according to their responses on decrease in yield of rice

Types of Rice	**Respondents**							
	No Decrease		**Low Decrease**		**Medium Decrease**		**High Decrease**	
	F*	P* **(%)**	F	P **(%)**	F	P **(%)**	F	P **(%)**
Aus	2	4	8	16	26	52	14	28
Aman	-	-	34	68	11	22	5	10
Boro	-	-	3	6	13	26	34	68

F* = Frequency, P* = Percentage.

4.3.8 Impact of industries on quality of rice

Rice grain quality was evaluated before and after industrialization through using four indicators, namely very good, good, bad and very bad (Table 23). The respondent opined that the quality of rice declined due to establishment of industries. It is to be noted that before industrialization, respondent's percipience on grain-size and shape (44 and 56%, respectively), taste (68 and 32%, respectively), color (42 and 58%, respectively), odor (40 and 60%, respectively) and market value (22 and 60%, respectively) was confined to only very good and good, respectively, although only 18% of the respondents opined that the market value was bad in previous. Lamentably, after industrial progression, only 8 and 2% of the respondents, respectively said that the size and shape, and the taste was very good, while no one opined as very good regarding grain color, odor and -market value. Although, perception on good grain size and shape (62%) as well as good grain color (60%) was enhanced from previous, but in terms of grain taste, odor and market value; 48, 58 and 68% of the respondents, respectively opined as bad. However, 8, 16, 12, 18, and 12% of the respondents, respectively, deemed that the size and shape, taste, color, odor and market value of rice grain deteriorated very badly at present after industrialization.

4.3.9 Problems related to production, socioeconomic and health and environment caused by industrial effluent (IE)

Several IE-induced productions, socioeconomic, and health and environment related problems were enlisted and acquired farmer's opinions with regards to lower, moderate and higher approval (Table 24). Within production-related problems, 45 and 5 respondents alleged that the soil fertility was reduced at higher and moderate extent, respectively, which made it ranked 1st within production-related problems and ranked 2nd within cumulated problems. Appertaining to farmer's opinions, higher input cost as well as low yield had a total score of 135 and 130, respectively, and became positioned as 2nd and 3rd within production-oriented problems, while 3rd and 4th within summative problems. However, deformed grain shape was the tiniest production-relevant problem, which positioned 11th across accumulative problems.

Within socioeconomic problems, low income considered as prime problem having total score of 120 and graded 6th in cumulative problems. Due to lower outcomes from agricultural activities, people were engaged to other occupation to diversify their income, which positioned 7th within cumulative problem with a score of 111. Nonetheless, social confliction is the least socioeconomic problem, which ranked 16th in overall complications.

Within the context of health and environment-related problems; greater extent of air, water and soil-pollution ranked 1st in both cases of internal- and overall-problems with total score of 147. Intrinsic to farmer's opinions, animal migration resultant from IE-contamination in both surface and aquatic environment positioned 12th within comprehensive-problems with total scores of 77. Dermal disease was the nominal problem within this category, which graded 15th in cumulative problems.

Table 23. Distribution of the respondents according to their response on size and shape, taste, color, odor and market value of rice before and after the establishment of industries

Rice quality	Rice				
	Categories	Before		After	
		F*	P* (%)	F	P (%)
Size and shape	Very good	22	44	4	8
	Good	28	56	31	62
	Bad	-	-	11	22
	Very bad	-	-	4	8
Taste	Very good	34	68	1	2
	Good	16	32	17	34
	Bad	-	-	24	48
	Very bad	-	-	8	16
Color	Very good	21	42	-	-
	Good	29	58	30	60
	Bad	-	-	14	30
	Very bad	-	-	11	12
Odor	Very good	20	40	-	
	Good	30	60	12	24
	Bad	-	-	29	58
	Very bad	-	-	9	18
Market value	Very good	11	22	-	-
	Good	30	60	10	20
	Bad	9	18	34	68
	Very bad	-	-	6	12

F* = Frequency, P* = Percentage.

Table 24. Rank order of the problems caused by industrial effluent

Sl	Problems	Extent of opinion			Score	Rank	Total Rank
		n = 50					
		Low	**Medium**	**High**			
Production related							
1	Low soil fertility in rice field	0	5	45	145	1	2
2	High input cost	0	15	35	135	2	3
3	Low yield	0	20	30	130	3	4
4	Increase attack of insect	15	30	5	90	5	9
5	Deformed shape of grain	22	24	4	82	7	11
6	Bad smell and taste	20	25	5	85	6	10
7	Low market price	3	20	27	124	4	5
Socioeconomic related							
8	Low income	2	26	22	120	1	6
9	Loss of land	6	32	12	106	3	8
10	Shifting to other occupations	5	29	16	111	2	7
11	Social conflict	40	10	0	60	5	16
12	Food crisis	32	16	2	70	4	13
Health and Environment related							
13	Dermal disease	38	11	1	63	4	15
14	Respiratory disease	35	12	2	65	3	14
15	Polluted air, water and soil	0	3	47	147	1	1
16	Migration of different animal sp.	28	20	3	77	2	12

4.3.10 Distal influence of industries on soil and water properties

Distance from the industry had substantial effects on the accumulation of heavy metals in both water and soils (Table 25). Overall, the accumulation of heavy metals seemed to reduce with increasing distance from the source of contamination. However, in both water and soils, higher concentration of Pb (42.11 and 72.63 ppm, respectively), Cd (2.27 and 4.75 ppm, respectively), and Ni (22.25 and 61.50 ppm, respectively) were observed in less than 10 m distance from the contaminated-industrial source followed by 10-20 m (40.00 and 55.26 ppm for Pb, 1.67 and 4.24 ppm for Cd, and 21.25 and 52.00 ppm for Ni, respectively). On the other hand, lower concentration of Pb (31.95 and 33.95 ppm), Cd

(0.75 and 1.41 ppm) and Ni (14.25 and 22.00 ppm) were found at above 40 m distance from the industry in both the water and soils, respectively.

Table 25. Effect of distance from industries on soil and water properties

Distance	**Pb (ppm) or (mg/kg) or (ml/L)**	**Cd (ppm) or (mg/kg) or (ml/L)**	**Ni (ppm) or (mg/kg) or (ml/L)**	**Pb (ppm) or (mg/kg) or (ml/L)**	**Cd (ppm) or (mg/kg) or (ml/L)**	**Ni (ppm) or (mg/kg) or (ml/L)**
	Water			**Soil**		
<10 m	42.11a	2.27a	22.25a	72.63a	4.75a	61.5a
10 - 20 m	40.00ab	1.67b	21.25a	55.26b	4.24a	52.0b
20 - 30 m	36.83bc	1.51b	19.00b	50.00b	3.43b	42.0c
30 - 40 m	34.78cd	1.21c	17.50b	40.37c	2.82c	34.0d
>40 m	31.95d	0.75d	14.25c	33.95d	1.41d	22.0e

Source: Ahmed *et al*., (2018)

DISCUSSION

Due to rapid industrialization, metal contamination of rice plant and grains is one of the crucial environmental problem in Bangladesh. Therefore, the present study was conducted to examine the effects of metal-containing polluted soils on growth and yield-related attributes of rice plants. Furthermore, questionnaire survey was also conducted to attain the perceptions of farmers in the metal-prone areas.

Rice (*Oryza sativa* L.) positioned second in the worldwide production of cereals and used as a staple food for half of the world population (Databases, 2007; Pandey and Dubey, 2019). Regrettably, industrial exploration in nowadays emerged as a solemn problem resulting contagion of agricultural land (Fahad and Bano, 2012; Fahad *et al*., 2013; Fahad *et al*., 2014; Fahad *et al*., 2015). Besides industries, rice fields are also contaminated with metals by irrigation with polluted water, excessive use of mineral fertilizers, pesticides containing metals, burning of fossil fuels, exhausts from power plants, and road traffic (Pandey and Dubey, 2019). When rice grown in polluted soils with heavy metals, these metals are usually taken up by the plants and get accumulated within the tissues that disturb the normal plant functioning by causing structural, physiological and functional alterations (Nagajyoti *et al*., 2010; Afshan *et al*., 2015; Shahzad *et al*., 2016, 2017; Fahad *et al*., 2019).

Empirical evidence showed that metals like Cd, Pb, Cu, Mn, Cr, Ni, Al, and the metalloid As decreased the germination of rice seeds and caused reduction in the growth of rice seedlings (Ahsan *et al*., 2007a, b; Maheshwari and Dubey, 2009; Pandey *et al*., 2013;

Srivastava *et al*., 2014). Growth inhibition of plants are often considering as the obvious visual evidence of metal toxicity (Sharma and Dubey, 2007, Keunen *et al*., 2011), which was also observed in our present study as evidenced by the attenuation of growth-related attributes under both metal- and only arsenic- contaminated soil. The higher values of plant height, number of effective tillers hill^{-1}, length of panicle, filled grains panicle^{-1}, thousand seed weight, grain and straw yields of *Boro* and T. Aman rice were recorded in non-polluted soil (S_1) and lower values of plant height, the number of effective tillers per hill, length of panicle, filled grains per panicle, grain and straw yields were recorded in polluted soils.

The reductions in plant growth parameters under metal-contaminated soils are primarily attributed to reduced photosynthetic-activities and -pigments, deficiency of plant mineral nutrition, and decreased activity of enzymes involved in CO_2 fixation (Chibuike and Obiora, 2014; Choudhury *et al*., 2011; Srivastava *et al*., 2014). Heavy metals are known to decrease the plasticity of cell walls, probably by direct binding to pectins and by promoting peroxidase activity in the cell walls and intercellular space; these peroxidases are essential for lignification and linkage between extensin and polysaccharides containing ferulic acid. All these metabolic changes inhibit plant growth and cell divisions, and disrupt morphogenesis (Bhalerao *et al*., 2015). Nevertheless, each of heavy metals have specific way in growth retardation of plants, which ultimately affects the yield of crops. For instance, cadmium (Cd) is one of the main pollutants in paddy fields, and extensively reported to reduce the rice growth and biomass (Li *et al*., 2012; Wang *et al*., 2014; Zhou *et al*., 2014; Mostofa *et al*., 2015; Rehman *et al*., 2015). Excessive Cd exposure (100 mg Cd kg^{-1} of soil) caused leaf chlorosis and necrosis (Liu *et al*., 2003) as well as disrupts some physiological process of plants, including gas exchange characteristics (net photosynthetic rate, stomatal conductance, transpiration rate, and water use efficiency) and decreased photosynthetic pigments (chlorophyll *a*, chlorophyll *b* and carotenoids) (Rascio *et al*., 2008; Wang *et al*., 2014). Cadmium also affects the uptake and translocation of essential nutrients by rice (Liu *et al*. 2003; Li *et al*., 2012).

In the current study, metal-contaminated soils showed higher concentrations of Cd in comparison to that of control pots that might be translocate to the upper parts of plants as evidenced by the lower grain yield and notable accumulation of Cd in both *Boro* and T. Aman rice grains. Irrespective of treatments, higher cadmium concentrations were recorded in *boro* rice grain in comparison to T. Aman rice grain. The higher levels of cadmium were mentioned in the fertilizer treatments where 100% chemical fertilizer was used. Resembling to the results, translocation of Cd to the above-ground parts of rice plants, and associated grain yield, quality and nutrient uptake reduction were also reported in several studies (Arao and Ae, 2003; He *et al*., 2006; Liu *et al*., 2007; Rodda *et al*., 2011; Li *et al*., 2012; Rizwan *et al*., 2016).

In this present study, *Boro* and T. Aman rice were grown in the arsenic contaminated soils by using different fertilizer and irrigation treatments. Higher *boro* and T. Aman rice yields were observed in the integrated use of fertilizer and manure treatment with the application of traditional irrigation. Irrespective of treatments, significant amount of Arsenic (As) was accumulated in *Boro* rice grain as the experimental soil background As was higher. Higher levels of grain arsenic accumulations were recorded in the inorganic fertilizer treatment where manure was not applied. Among the inorganic fertilizer treatments, higher grain As levels were observed in the treatment (T_2:$N_{150}P_{60}K_{60}S_{20}Zn_3$), where higher levels of phosphatic fertilizer was used. It indicated that phosphorus and arsenic both were accumulated as anionic form, so the arsenic availability in the soil solution was increased due to the application of higher rates of phosphatic fertilizer in soil. Arsenic contamination of the soil and water environments has become a global problem due to its toxicity, long-term persistence, and carcinogenic nature. Arsenic-rich groundwater is not only consumed for drinking but also for crop irrigation, specifically for paddy rice in As-affected countries worldwide (Raza *et al*., 2017). Arsenic-rich groundwater is used extensively, mostly in dry season, for irrigation of rice plants in India, Pakistan, and Bangladesh (Shakoor *et al*., 2016). Natural concentrations of As in paddy soils ranges from 4-8 mg kg^{-1}, which may incline up to 83 mg kg^{-1} in the many parts of the world where As-contaminated groundwater is applied for irrigation of paddy soils (Patel *et al*., 2017). Due to the presence of high As contents in paddy soils originating from As-contaminated irrigation water, the rice accumulates comparatively higher levels of As (20-22 times greater) than other staple crops (Dahlawi *et al*., 2018).

Rice is cultivated as a lowland staple crop in flooded paddy fields in oxygen deficient environments where As is mobilized more as compared to oxygen-rich environments (Williams *et al*., 2005; Abbas *et al*., 2018). In the reduced conditions such as in flooded paddy soils availability/ mobility of arsenite (As^{III}) is much greater compared to that of arsenate (As^{V}), owing to the process of reductive dissolution of Fe minerals (oxides and hydroxides) (Niazi *et al*., 2011; Shakoor *et al*., 2018). This process of reductive dissolution, occurring under oxygen-deficient conditions, significantly increases As bioavailability to rice plants, thus, causing high As uptake in rice grains (Bhattacharya *et al*., 2010; Ahmed *et al*., 2011). Rice grain accumulates 10 folds higher As than other cereal crops (Williams *et al*., 2007). Concentrations of As in rice grains is collectively influenced by the features of the soil, crop management, rice varieties, and conditions prevailing in paddy soils (Panaullah *et al*., 2009). The data are much limited about how rice plants uptake and translocate As into their grains and other parts. The translocation or uptake of As in rice crops is significantly impacted by As speciation in the rhizosphere (Arao *et al*., 2011). Two major pathways for As uptake in rice plants include: (1) the phosphate transport channels, as As^{V}, which is an analogue of phosphate, and (2) via silicon (Si) channels as As^{III} and methylated As such as monomethylarsonic acid and dimethylarsinic acid, which are absorbed into the roots by the aquaporin system used for silicate transport (Wu *et al*., 2011; Abbas *et al*., 2018).

Toxicity symptoms such as stunted growth, brown spots, and scorching on leaves of rice plants were observed in soils containing >60 mg kg^{-1} total As (Khan *et al*., 2010). In conventional paddy fields of Bangladesh, a decrease in rice yields from 7.5 to 2.5 t ha^{-1} was reported when soil As concentration were increased from 12 to 60 mg kg^{-1} (Duxbury and Panaullah, 2007). Similar to our outcomes, number of reports showed drastic reduction in plant height, productive tiller number, shoot biomass and grain yield due to an increase in soil As concentrations (Hossain *et al*., 2007; Khan *et al*., 2009; Wang and Forsyth, 2006; Syu *et al*., 2014; Yu *et al*., 2017).

In the present study, higher levels of Zn concentrations were observed in *Boro* and T. Aman rice grain grown in arsenic contaminated soil with inorganic fertilizer treatments. The highest level of Zn was accumulated in alternate wetting drying condition with the application of chemical fertilizer. Similarly, higher lead accumulations were noticed in T. aman rice grain with the inorganic fertilizer treatments and lower levels lead were accumulated in the fertilizer treatments where organic plus inorganic fertilizers were used. Similar to Zn accumulation, the highest level of Pb was accumulated in alternate wetting drying condition with the application of chemical fertilizer.

Lead is one of the most hazardous metal and ranked second after arsenic due to its potential of toxicity to plants and human beings as well as occurrence and distribution over the globe (Grover *et al*., 2010; Shahid *et al*., 2011). Rice exposed to lead showed alternations of morpho-physiological and biochemical processes, including seed germination and seedling growth, plant phenology, and root/shoot ratio (Mishra and Choudhari, 1998; Zeng *et al*., 2006; Li *et al*., 2012; Ashraf *et al*., 2015). The primary cause of cell growth inhibition resultant reduced plant growth arises from a lead-induced simulation of indol-3 acetic acid (IAA) oxidation (Kalaivanan and Ganeshamurthy, 2016). Reduced photosynthetic capacity, distorted chloroplast ultrastructure, restrained chlorophyll synthesis, repressed electron transport, and reduced activity of enzymes involved in the Calvin cycle are also noticed in plants when exposed to Pb stress (Sharma and Dubey, 2005; Kalaji and Loboda, 2007).

Lead toxicity in soil further impaired plant nutrition, affects plant-nutrient relationship (Gopal and Rizvi, 2008), and changes internal nutrient ratios among the plant tissues (Kabata-Pendias and Pendias, 1992). Research done so far regarding lead toxicity and its relation with plant mineral nutrition is not enough to make a definite conclusion about lead mechanism of nutrition imbalance; but it can be stated from the previous work that lead influences mineral uptake by plants. It restricts the entry of divalent cations such as Ca^{2+}, Mg^{2+}, Fe^{2+}, Zn^{2+}, and Mn^{2+} and anions like NO_3^- in various plants including rice (Chatterjee *et al*., 2004). Two mechanisms might be involved in reduced uptake of mineral nutrients. First mechanism known as physical depends on size of metal ions and second is the chemical one that might be due to metal-induced changes in the cell metabolism by disrupting cell membrane and alteration in enzymatic activities (Ashraf *et al.*, 2015). However, it is hard to conclude that reduction in ion uptake is due to blockage of nutrients through roots, reduction in translocation from roots to shoots, or alteration in distribution pattern of metal ions in the plants. In the present study, higher accumulation of Pd might be severely impeded the growth, morphology and yield of rice (Table 3.2, 3.6), which also confer by the higher Pb accumulation in the grains of T. Aman rice.

Although Zn is an essential nutrient for plants and obligates in many metalloenzymes, exposure to elevated Zn concentrations might cause plant toxicity (Islam et al., 2016). Increased plant Zn concentrations induced toxicity in plants is based on the fact that these ions in cells are competing for binding sites intended for other biologically active ions (Kramer, 2010). The toxicity may inhibit many plant metabolic functions, resulting in chlorosis of younger leaves (probably the consequence of lower uptake of Fe^{2+} and Fe^{3+}) (Ren *et al*., 1993; Ebbs and Kochian, 1997; Nagajyoti *et al*., 2010) and the reduction of plant biomass and inhibition of root growth (Broadley *et al*., 2007; Sturikova *et al*., 2018). In the present study, higher accumulation of Zn might be severely impeded the growth, morphology and yield of rice, which also confer by the higher Zn accumulation in the grains of both *Boro* and T. Aman rice.

Empirical evidence showed that the productivity of rice has been severely threatened by on-going heavy metal contamination in agricultural soils, thereby jeopardizing the food security of the growing population. In the present study, higher levels of lead, cadmium, chromium and nickel were found in the industrially polluted soils. To curtail the heavy metal-induced crop losses, remediation measures are eminent need. Although several technological approaches have been developed tremendously in nowadays to dealt with this problem, agronomic measures, including fertilization and water management practices could also play a significant role in decreasing the uptake of toxic heavy metals in rice grains, especially for poorly-developed countries like Bangladesh (Shakoor *et al*., 2019). Importantly, organic amendments like compost and cowdung application together with mineral fertilizers enhances the bioremediation of heavy metal(loid)s through various processes, including immobilization, reduction, volatilization and rhizosphere modification (Park *et al*., 2011).

In the present study, half portion of the recommended doses of chemical fertilizers along with 6 ton of cowdung ha^{-1} found effective in reducing the toxicity of heavy metals in rice production compared to that of other doses of fertilizers in polluted soils. A number of studies have documented the potentiality of various organic and inorganic soil amendments in reducing the bioavailability of metal(loid)s in soil (Pérez-de-Mora *et al*., 2006; Paulose *et al*., 2007; Kumpiene *et al*., 2007; Park *et al*., 2011). For example, various phosphate compounds have been found to be very effective in the immobilization of Pb in soils (Arnich *et al*., 2003; Chen *et al*., 2003; Cao *et al*., 2009).

In the literature, proper nutrition of essential plant nutrients such as N, Zn, Fe, and Se in reducing Cd toxicity in rice is well reported (Rizwan *et al*., 2016). Moreover, organic matter content has a vital role in deducing the mobility and availability of Cd in soil. It reduces the bioavailable Cd in soil through adsorption or forming stable complexes with humic substances (Halim *et al*., 2015). This influence of organic matter is in favor of decreasing Cd accumulation in rice and has been verified by Xu *et al*. (2010), who found a remarkable reduction of Cd levels in grains, straws and roots of rice in the existence of organic acids and ethylenediamine tetraacetic acid (EDTA). Wu *et al*. (2011) and Juang *et al*. (2012) reported that compost application decreased bioavailable Cd in soils and its uptake by rice plants as compared to control. Banks *et al*. (2006) observed that application of composted cow manure reduced the Chromate [Cr(VI)] ion leaching in soils because of reduction followed by retention on cation exchange sites or precipitation. Substantial studies noted soil pH is negatively correlated with the availability of heavy metals in plants (Kirkham, 2006; Zeng *et al*., 2011). Moreover, flooding increases the pH of soil, which in turn decreases the availability of heavy metals.

In the present study, application of irrigation as a form of continuous flooding (2-3 cm water) along with 50% RDCF + 5 ton Compost/ha showed significant result in response to growth-related parameters and yield of rice grains, which were grown in arsenic contaminated soils (Table 3.5, 3.6). This result revealed that balanced and coordinated application of fertilizer along with compost and proportionate use of traditional irrigation may reduce the harmful effects of As present in soil and also reduce the accumulation of this metal in rice grains. Honma *et al*. (2016) performed water management experiments and found that the conventional irrigation method and intermittent irrigation at different intervals employed notable changes in rice grain As concentrations through the changes in Eh, pH, and dissolved Fe^{2+} concentrations in soils. Similarly, Hu *et al*. (2013) demonstrated that the reproductive growth stage of rice is crucial to controlling As accumulation. They also found that the conventional irrigation method, until full tillering stage, followed by intermittent irrigation leads to low As and high grain yield. Moreover, the potential value of organic amendments in the volatilization of Arsenic from soil was observed by Cao *et al*. (2003) where, As loss up to 16% from the compost amended soils was attributed to microbially-mediated As volatilization in the chromated–copper–arsenate contaminated soil.

However, in order to get the ground truth information, a questionnaire survey have also be done in the industrial-contaminated area of Gazipur district. Distance from the source of contamination act as a key driving force towards pollution intensity in both soil and water. The results of our survey study also supported these phenomena. The respondents observed that the increase in distance from industries reduces the contamination level of heavy metals in soil and water might be attributable to the leaching loss of effluents in vertical levels of soil rather than horizontal level. Tabassum *et al*. (2015) found that the level of Pb and Cd were beyond the permissible limit at closest distance (0 m) from the industry, while least value was noted at 300 m distance. Naser *et al*. (2012) also reported the decrease in concentration of heavy metal (Ni, Pd and Cd) with increasing distance from transport ways.

Soil is the important medium of plant growth and the controller of crops’ quantity and quality. Continuous throwing of industrial wastes on surface soil reduces its quality, which ultimately reduces the yield of crops. Most of the surveyed respondents opined that the color and odor of the soils deteriorated after establishing of industry as well as continuous discharge of industrial effluents on rice fields is deteriorating the quality crop production and declining the overall yield of rice, which directly effects the economy of the rice producers due to the low price at market. The cause of this deterioration in soil and rice quality and quantity might be due to the discharge of a large number of heavy metals from the industrial wastes, which accumulated in the soils and water, and entered in the plants and disrupted their growth and production. Corroborated to our findings, similar opinion of the respondents regarding deuteriation of soil quality have also been reported by Hossain *et al*. (2010).

Surface water is an inevitable source of irrigation as well as household usages, however, this surface water being deteriorate notoriously day by day due to anthropogenic activities. From our result, it was manifested that before industrial exploration, the color and odor of the surface water was very good and good for bathing, irrigation, domestic activities, cooking and even drinking purpose, which turned to bad and very bad after establishment of industry (Table 3.18). However, in case of ground water, the perception of the people regarding color and odor was mostly very good before arrival of the industry, but after setting industry it turned to good from very good and even bad quality. The deterioration of the color and odor of the surface and ground water might be associated with indiscriminate discharge of untreated industrial wastes, which later than inter-mixed with surface water as well as leached into the soil and ultimately making these water untenable for usage. Hossain *et al*. (2010) also reported that the responded of their surveyed area opined worse quality of surface water, however, deterioration of ground water quality was not so prominent like our study outcomes.

Size and shape, taste, color, odor are the key determinants of quality rice, which sturdily regulate the market value. However, unplanned disposal of industrial waste around the industrial area led to accumulate heavy metals that severely languish the soil quality, and when crops grown on that area, heavy metals may translocate to the upper part of the plant, even deposit in grain, and thereby dwindle the grain quality. Respondents of our present study also confer that the grain quality as well as yield was not alike at previous and deteriorate day by day with enhancing industrial dumping. Survey outcomes of Hossain *et al*. (2010) also endorse the similar findings in their study areas.

Untreated and unplanned industrial discharges deteriorate not only the quality of soil and crop environment but also directly affects the human, animal and their environment and it is most harmful and ultimate impact of industrial wastage. The results evident that consumption of effluent wasted water and crops hampered the respiratory system and dermis of the human body. However, migration of animals also observed from polluted area, which ultimately affects the ecosystem. Due to industrialization, fertility status of the soils declining day by day, which upsurge the input cost, while due to industrial effluent-induced deform shape of grain as well as unpleasant taste and odor, market price of that rice become low, and farmers lost their aspiration to rice production. Consequently, food crisis may happen in some parts of robust industrial area, which provoke some people migrated to another occupation as a way of living. The results of the present study further supported by the results of Hossain *et al.* (2010).

CHAPTER V

SUMMARY

Three experiments – two in the net house by using polluted soils and one field survey were conducted for achieving the objectives of the present study.

5.1 Effect of different fertilizers and manures on yield and metal accumulation in rice grown under different polluted soils of Gazipur industrial areas

Variation in polluted soils and fertilizer regimes significantly influenced the yields and yield- attributes of boro rice. In case of soil pollution, all the parameters showed higher values in non-polluted soil (S_1) and lower values in polluted soil (S_3). The highest and the lowest values of different yield attributes were observed in T_3 and T_4 treated pots, respectively due to the influence of different fertilizer effects. The 1000-grain weights were significantly influenced among the treatments, and the highest and lowest values were documented in T_2 and T_0 treated pots, respectively. For combined effect of polluted soils and fertilizer treatments, the highest and lowest plant height (151.27 and 124.87 cm) were measured in T_2S_1 and T_0S_3 treatments, respectively. Maximum number of total tillers hill^{-1} (57.00) was recorded in T_2S_1 and the minimum (28.33) was found both in T_1S_3 and T_0S_3 treatments, respectively. The highest and the lowest number of effective tillers hill^{-1} (51.33 and 23.00) were recorded in T_2S_1 and T_0S_3 treatments, respectively. The highest and lowest length of panicle for boro rice (35.01, and 25.63 cm) were observed in T_2S_1 and T_0S_3 treatments, respectively. However, the maximum (313.87 and 266.20) and minimum (24.00 and 23.07) number of filled- and unfilled-grains panicle^{-1} were recorded in T_2S_1 and T_0S_3 treatments, respectively. Due to the combined effects of polluted soils and fertilizers gradients, the weights of thousand grains varied significantly. It was the highest (21.33 g) as reflected in both T_2S_1 and T_1S_1 treated pots and the lowest value (16.50 g) was obtained in both T_1S_3 and T_0S_3 treatments. The highest (173.23 and 96.40 g pot^{-1}) and the lowest (55.43 and 22.57 g pot^{-1}) yields of straw and grain were found in T_2S_1 and T_0S_3 treatments, respectively.

The yield and yield-attributes of T. Aman rice was significantly influenced due to the variation of both polluted soils and fertilizer treatments. The main effect of polluted soils indicated that for all the highest and lowest values of plant height, total number of effective tillers hill^{-1}, effective tillers hill^{-1}, panicle length, thousand-grain weight, filled and unfilled grains panicle^{-1}, grain and straw yield, were observed in non-polluted (S_1) and highly polluted soil ($S_{3)}$ treatments, respectively. The highest and lowest values of the above-mentioned parameters were noted in T_2 and T_0 treated pots, respectively due to the application of different fertilizer treatments. The combined effect indicated the highest plant height (153.30 cm) in T_2S_1 and the lowest plant height (124.78 cm) in T_0S_3 treatments, which was statistically similar to T_1S_3 (125.30 cm) treatment combination. The highest (54.33) number of total tillers per hill was found in T_2S_1 and the lowest (25.00) in T_0S_3. However, the highest (50.00) number of effective tillers hill^{-1} was counted in T_2S_1 treatment, and the lowest (20.67) in both T_0S_3 and T_1S_3 treatments. The highest and lowest lengths of panicle for T. Aman rice (46.43, and 25.65 cm) were observed in T_2S_1 and T_0S_3 treatments, respectively. Number of filled-grains panicle^{-1} were found maximum (190.53) in T_2S_1 which was followed by T_1S_1 (188.20) and minimum (94.21) in T_0S_3 treatment. The higher unfilled grains panicle^{-1} (167.20) and yields of straw (136.80 g pot^{-1}) and grains (88.75 g pot^{-1}) were observed in T_2S_1 treatment, while the lowest values of the above parameters were observed (102.13, 49.43 g pot^{-1} and 15.90 g pot^{-1}) in T_0S_3 treatment.

Maximum weight of thousand grains (22.83 g) was found in both T_1S_1 and T_2S_1 and minimum (17.33 g) in both T_0S_3 and T_1S_3 treatments, respectively.

Different polluted soils and fertilizer treatments significantly influenced the concentration of Cd and Zn in boro rice grains and Cd, Zn, and Pb in T. Aman rice grains. In case of polluted and non-polluted soils for boro and T. Aman rice, the highest and lowest concentrations of heavy metals were noted in S_3 (polluted soil 2) and S_1 (non-polluted soil) treated pots, respectively. Impact of different fertilizer treatments for both boro and T. Aman grains resulted, the highest and the lowest concentrations of heavy metals in T_1 and T_0 treated pots, respectively. However, for interaction effects of polluted soils and fertilizer levels, the highest and the lowest Cd concentrations (0.33 and 0.06 ppm) were recorded in T_1S_3 and T_0S_1 treatments, respectively in boro rice. In case of Zn for boro rice, the utmost and the lowermost values (40.57 and 13.74 ppm) were observed in T_1S_3 and T_0S_1 treatments, respectively. The Cd accumulation in T. Aman grains was found the highest (0.07 ppm) in T_1S_3 and the lowest (0.03 ppm) in T_0S_1 treatment. Moreover, the highest and the lowest accumulation of Zn (45.00 and 32.41 ppm) in T. Aman rice grains were recorded in T_1S_3 and T_0S_1 treatments, respectively. The highest Pb (0.14 ppm) content was found in T_1S_3, which was statistically similar to T_2S_3 (0.13 ppm) treatment, and the lowest one (0.06 ppm) was found in both T_2S_1 and T_0S_1 treatments.

Polluted soils and fertilizer gradients individually and combinedly affected the soil properties significantly. In case of individual effects of polluted soils, parameters, including pH, OM (%), K meq/100g), N (%), P (ppm), S (ppm), Cu (ppm), Mn (ppm), Fe (ppm), Ca (ppm) and Mg (ppm) were reported higher in S_1 soil treated pot, while lower values of those respective parameters were recorded in S_3 treated pots. In contrast, the higher and lower values of Zn, Cd, Pb, Cr and Ni were found in S_3 (polluted soil 2) and S_1 (non-polluted soil) treated pots, respectively. The main fertilizer effects indicated that for almost all the parameters (pH, OM, K, P, S, Cu, Mn, Fe, Ca and Mg) the highest and lowest concentrations in soil were found in T_2 and T_0 treated pots, respectively. In addition, for N, the highest concentration was documented in T_2 and the lowest was recorded in both T_0 and T_1 treated pots. For Cd, Pb, Cr and Ni, the highest and lowest values were found in T_1 and T_0 treated pots, respectively. The combined effects of both polluted soils and fertilizer gradients indicated the highest and lowest pH (5.87 and 5.61) values in T_2S_1 and T_0S_3 treatments, respectively. The highest and lowest values of OM (2.42 and 1.72%) were observed in T_2S_1, and T_0S_3 treatment, respectively, whereas the lowest one was statistically similar to T_1S_3 (1.75%) treatment. The maximum K and N concentrations (0.24 meq/100g and 0.14%, respectively) were found in T_2S_1 treatment, which was statistically similar to T_1S_1 treatment. However, the lowest K content (0.18 meq/100g) was observed in T_1S_3, which was statistically similar to T_0S_3 treatment. Whereas, the lowest N content (0.10%) was found in T_0S_3, T_1S_3 and T_2S_3 treatments. The highest and lowest P concentrations were found in T_2S_1 (38.20 ppm) and T_0S_3 (24.28 ppm) treatments, and the highest concentrations of P was statistically similar to T_1S_1 (37.47 ppm) treatment. In case of S the maximum value (33.33 ppm) was documented in T_2S_1 treatment, whereas the lowest value (24.35 ppm) was found in T_0S_3 treatment. However, the highest concentrations of Cu (55.98 ppm), Mn (85.00 ppm), Fe (1525.10 ppm) and Ca (57.87 ppm) were observed in T_2S_1 treatment and the lowest values of those respective parameters were recorded in T_0S_3 treatment. The maximum (9.48 ppm) and minimum (7.06 ppm) Mg concentrations were obtained in T_2S_1 and T_0S_3 treatments, respectively, while the minimum (7.06 ppm) content was insignificantly followed by T_1S_3 (7.18 ppm) and T_2S_3 (7.34 ppm) treatments. For Cd, the augmented (0.31 ppm) and abated (0.22 ppm) values were observed in T_1S_3 and T_0S_1 treatments. The highest Cd content was followed by T_2S_3 (0.30 ppm). The highest Zn (20.17 ppm), Pb (37.04 ppm), Cr (73.53 ppm) and Ni (16.75 ppm) concentrations were recorded in T_1S_3 (Polluted Soil 2 plus 100% RDCF) treatment combination, whereas the lower concentrations (14.76, 21.15, 43.89 and 11.05 ppm, respectively) were documented in T_0S_1 (Non-polluted soil plus control) treatment.

5.2 Effect of irrigation and different sources of fertilizer and manure on the yield of rice and accumulation of metals in rice grown in arsenic contaminated soils of Naraynganj

The influences of irrigation and fertilizer treatments significantly influenced the yields and yield- attributes of boro rice. Due to the main effect of fertilizers, all the parameters showed higher and lower values in T_4 and T_0 treated pots, respectively. There was no significant change in thousand-grain weight among the treatments. In case of the impact of irrigation treatments, the highest and lowest values of all parameters were observed in I_1 (traditional irrigation) and I_2 (alternate wetting and drying) treated pots, respectively. In case of interaction effects, maximum plant height (79.00 cm) was observed in T_4I_1 treatment, followed by T_3I_1 (77.98 cm), T_2I_1 (77.66 cm), T_1I_1 (77.37 cm) and T_0I_1 (77.25 cm), whilst the lowest one (66.60 cm) was reported in T_0I_2, followed by T_1I_2 treatment (67.33 cm). The highest (38.33) and the lowest (23.30) total number of tillers hill^{-1} were observed in T_4I_1 and T_0I_2 treatments, respectively. However, the maximum (33.00) and minimum (18.67) number of effective tillers hill^{-1} were found in T_4I_1 and T_0I_2 treatments, respectively. While the lowest one was followed by T_1I_2 (19.33). The maximum (24.39

cm) and minimum (22.42 cm) length of the panicle were reported in T_4I_1 and T_0I_2 treatments, respectively, whereas the highest one was statistically similar with T_3I_1 (23.98 cm) and T_2I_1 (23.95 cm) treatments. Higher number of filled-grains panicle^{-1} and maximum yield of straw (116.18 and 78.83 g pot^{-1}, respectively) were observed in T_4I_1 treatment, followed by T_3I_1 (115.59 and 78.80 g pot^{-1}, respectively). However, the maximum (30.25 and 97.85 g pot^{-1}, respectively) and minimum (17.89 and 24.23 g pot^{-1}, respectively) number of unfilled grains panicle^{-1} and grain yield were observed in T_4I_1 (Continuous flooding plus 50% RDCF + 5-ton compost/ha) and T_0I_2 (Alternate wetting drying plus control) treatments, respectively. The highest (20.17 g) and the lowest (18.44 g) weight of thousand grains were recorded in T_4I_1 and T_0I_2 treatments, respectively. The T_4I_1 treatment increased the growth and yield in comparison to other treatment.

The yields and yield-contributing characters of T. Aman rice were significantly influenced due to the influences of different irrigation and fertilizer gradients. The highest and lowest values of all the parameters studied were observed in T_4 and T_0 treatments, respectively due to the main effect of different fertilizer treatments. Similarly, the highest and the lowest values of all the parameters were observed in I_1 and I_2 treated pots, respectively. However, 1000 grain weight was not varied significantly due to any one of the treatments either fertilizer treatment or irrigation impact even in the interaction effects treatments. The combined effect of both the factors reflected the highest (128.93 cm) and the lowest (106.00 cm) plant height in T_4I_1 and T_0I_2 treatment combinations, respectively. Maximum (34.33) and minimum (19.33) total number of tillers were observed in T_4I_1 and T_0I_2 treatment combinations, respectively. However, the highest (30.00) and the lowest (15.67) number of effective tillers hill^{-1} were observed in T_4I_1 and T_0I_2 treatment combination, respectively, and the lowest one (15.67) was statistically similar to T_1I_2 (16.33) treatment combination. The highest (30.90 cm) and the lowest (23.05 cm) panicle length were noticed in T_4I_1 and T_0I_2 treatments, and the maximum one was followed by T_3I_1 treatment combination (29.93 cm). However, the highest number of filled- and unfilled-grains panicle^{-1} (324.87 and 108.57, respectively) were recorded in T_4I_1 treatment, whereas the lower most numbers (195.60 and 33.70, respectively) were counted in T_0I_2 treatment. Numerically the maximum (20.17 g) and minimum (19.33 g) weight of thousand grains were observed in T_4I_1 and T_0I_2 treatments, respectively. The maximum straw- and grain-yields (78.27 and 55.07 g pot^{-1}) were obtained in T_4I_1 (Continuous flooding plus 50% RDCF + 5-ton compost/ha) treatment and the minimum were found in T_0I_2 (Alternate wetting drying plus control) treatment (23.60 and 5.60g pot^{-1}).

Variations of irrigation methods and fertilizer treatments brought significant changes in the concentration of Cd, Zn, and As in boro rice grains and Cd, Zn, and Pb in T. Aman rice grains. The highest and lowest concentrations of heavy metals were noted in T_2 and T_0 treated pots, respectively due to the different fertilizer treatments in both boro and T. Aman rice grains. Similar to the influences of fertilizer gradients the highest and the lowest concentrations of heavy metals (Cd, As and Zn in boro rice grain; and Cd, Zn and Pb in T. Aman rice grain) were noted in I_2 and I_1 treated pots, respectively due to the main effect of different irrigation methods. Pertaining to the interaction effects for boro rice grains, the highest Cd (0.08 ppm) was recorded in both T_1I_2 and T_2I_2 treatments, whilst the lowest one (0.03 ppm) was found in T_0I_1. However, the higher and the lower concentrations of As in boro rice, (0.27 and 0.18 ppm) were estimated in T_2I_2 and T_0I_1 treatments, respectively. In case of T. Aman grains, the higher accumulation of Cd (0.26 ppm) was documented in T_2I_2, and the lower (0.14 ppm) values were observed in several treatments, including T_0I_1, T_3I_1 and T_4I_1 treatments. The maximum (0.142) and minimum (0.002) concentrations of Pb were observed in T_2I_2 and T_0I_1 treatments, respectively. However, in both boro and T. Aman rice grains, the highest (38.50 and 30.77 ppm, respectively) and lowest (17.98 and 19.14 ppm, respectively) concentrations of Zn were recorded in T_2I_2 and T_0I_1 treatments, respectively.

Variations in irrigation and fertilizer treatments significantly influenced the soil properties. In response to fertilizer gradients, all the parameters studied in the experiments showed higher values in T_4 treated pots and lower were in T_0 treated pots. The highest N concentration was found in T_4**,** T_3 and T_2 treatments. Further, due to irrigation methods, for all the parameters, the highest and the lowest values were documented in I_1 and I_2 treated pots, respectively. However, for combined effect of fertilizer and irrigation gradients highlighted the highest and the lowest pH values (6.33 and 6.06) in T_4I_1 and T_0I_2 treatments, respectively. For OM percentage, K and P, the highest contents (2.00%, 0.13 meq/100g and 63.33 ppm) were recorded in T_4I_1 treatment. However, for OM percentage and K, the lowest values (1.31% and 0.09 meq/100g, respectively) were found in both T_0I_2 and T_1I_2 treatments, and for P the abated value (43.96 ppm) was found in T_0I_2 treatment. In case of N, the highest value (0.12%) was recorded in T_4I_1 treatment, which was statistically similar to T_3I_1 (0.10%) and the lowest (0.08%) were observed in the treatments of T_0I_2, T_1I_2, T_2I_2, T_3I_2 and T_4I_2. The maximum (9.54 ppm) and the minimum (3.00 ppm) values of S were obtained in T_4I_1 and T_0I_2 treatments, respectively. The combined application of fertilizer and manure with continuous flooded irrigation improved soil fertility status.

5.3 Assessment of toxic metals in wastewater on the livelihood and food security of the local people around the industrial area

The highest proportion (52%) of the respondents in the studied area was in the middle-aged group followed by 30% under old-aged, and the last 18% were belonged to young-aged. About 36% of the respondents had no schooling and 32% could sign only, while 22% were primarily educated and the rest 6 and 4% of the respondents achieved secondary education, and S.S.C and above, respectively. Among the respondents, 64% were having medium sized family and 20% having small. Only 16% were having large sized family. For augmenting their income other than farming practices, most of the respondents were involved in driving (36%) followed by fishing (32%), business (22%) and day laboring (10%) professions as a secondary occupation.

The highest percentage (36%) of the farmers belonged to small farm size, while 32 and 10 percent farmers belonged to the marginal and medium farm categories and 22% were landless, whereas no respondents were found under large size farm category. In respect to annual income, majority of the respondents (38%) were in high category followed by medium (36%), and the rest of the respondents (26%) belonged to low category income.

Industrial effluent (IE) contaminated the rice field in a number of ways. Among the respondents, 60% agreed that IE-induced attenuation of the soil fertility in the rice field and increased production cost of rice. Turning to the deterioration of rice quality due to IE-induced contamination, 70% of the respondents agreed with the opinion, while 20% strongly agreed. Rice fields contaminated by IE lead to reduce yields and poor appearance of grain as affirmed by 40% of the respondents for both cases, which lead to attenuation of price value. Interestingly, half of the respondents still believed that the contaminated water for irrigation purpose was not harmful. Although, 40 and 50% of the respondents strongly- and moderately-agreed that rapid industrialization acted as key stimuli in contamination of irrigation water. Eventually, production scenario of rice in IE-contaminated area become worsen day-by-day, which had been agreed by 50% of the respondents. Accordingly, peoples are not willing to grow rice as before, which had been strongly- and moderately-agreed by 26 and 40% of the respondents, respectively. Furthermore, 50 and 20% of the respondents moderately- and strongly-replied that they were not aware about this due to the limited information they had regarding the negative effects of IE-induced contamination of rice fields.

Among the respondents, majority (60%) had a favorable perception on impact of industrial effluent contamination in rice production followed by unfavorable (24%) and highly favorable (16%) perceptions. Ninety percent respondents opined that soil-color and -odor were very good before the establishment of industry and deterioration of color and odor took place after industrialization. However, percent of respondent’s opinions regarding very good soil color were dipped down to 60%, whilst for odor it reached to 70% after built up of industries.

Farmers perception regarding changes in surface watercolor and -odor after establishment of industries was found quite negative than before exploration of industry. In respect of drinking watercolor and -odor, people’s previous opinions before inauguration of industry were very good (84 and 88%, respectively) and good (16 and 12%, respectively) that turned to bad (64 and 52%, respectively) and very bad (36 and 48%, respectively) after exploration of industry. Similar concept was observed in case of cooking watercolor and -odor, where very good (58 and 66%, respectively) and good (42 and 34%, respectively) opinions of the respondents changed to bad (74 and 78%, respectively) and very bad (26 and 22%, respectively) after built up of industries. For the purpose of domestic usage of water, after industrial exploration, good (66 and 18%, respectively) and very good (34 and 82%, respectively) opinions regarding watercolor and -odor were changed to bad (24 and 36%, respectively) and very bad (76 and 64%, respectively). In respect of surface water uses for irrigation, very good (76 and 80%, respectively) and good (24 and 20%, respectively) experience of farmers regarding color and odor of water had turned to bad (88 and 80%, respectively) and very bad (4 and 60%, respectively) after industrial establishment. Moreover, respondents' conceptions like very good (68 and 16%, respectively) and good (32 and 84%, respectively) of the color and odor of surface water for bathing purpose changed to bad (72 and 88%, respectively) and very bad (28 and 6%, respectively) after industries development.

In response to changes in ground watercolor and -odor after industrialization in the study area, respondent's response was not so negative attitude towards surface watercolor and -odor. In case of drinking watercolor and -odor, people's perception was very good (86 and 92%, respectively) and good (14 and 8%, respectively) before industry development, whereas after industrial exploration, most of the peoples opined as good (68 and 54%, respectively) instead of very good (26 and 34%, respectively) and even some commented it as bad (6 and 12%, respectively). Similar to that of drinking watercolor and -odor, before establishment of industries, very good (88 and 50%, respectively) and good (12 and 50%, respectively) perceptions regarding cooking water-color and -odor turned to good (72 and 32%, respectively) in lieu of very good (28 and 60%, respectively) after industrialization. In case of domestic usage of water after industrial exploration, very good (80 and 86%, respectively) and good (20 and 14%, respectively) opinions regarding watercolor and -odor were changed, and most of respondents opined as good (72 and 72%, respectively) and some gave consent as very good (28 and 22%, respectively). In respect of ground water uses for irrigation, very good (86 and 80%, respectively) and good (14 and 20%, respectively) experience of farmers regarding color and odor of water had turned to good (76 and 86%, respectively) and very good (24 and 14%, respectively) after industrial establishment. Similarly, respondents very good (82 and 78%, respectively) and good (18 and 22%, respectively) perception of the color and odor of ground water for bathing purpose changed to good (76 and 14%, respectively) and very good (24 and 86%, respectively) after the development of industries in the study area.

Fifty-two percent of the respondents reported the moderate decrease in aus rice yield due to impact of industrial effluent, while for aman rice, majority of the respondents (68%) though as said the minimum extant of yield reduction and the yield of boro rice was severely impeded. Before industrialization, majority of the respondents' percipience is that the rice grains had good size and shape (56%), color (58%), odor (60%), market value (60%) as well as very good taste (68%). However, after industrial progression, perception on good grain size and shape as well as good grain color was enhanced (62 and 60%, respectively) from previous, but in terms of grain-taste, -odor and -market value; 48, 58 and 68% of the respondents, respectively opined as bad. It is worth noting that even 8, 16, 12, 18, and 12% of the respondents, respectively reported very bad at present after industrialization in terms of size and shape, taste, color, odor and market value of rice grain.

Industrial effluent caused a number of production-, socioeconomic-, and health & environment-related problems. And overall, sixteen problems were taken into consideration. Afterwards, farmers opinions were collected against each problem in terms of lower, moderate and higher persistence. Reduced soil fertility, augmented input cost, and lower yield of rice were the most prominent production-oriented problems having score of 145, 135 and 130 with the position of 2nd, 3rd and 4th in terms of severity within the cumulative problems. However, industrial effluent-induced changes in grain shape were the least important production-related problem, which ranked 11th within the cumulative problems.

Decrease in production owing to industrial effluent led to lower income and to augment family income peoples shifts their main profession and engaged to different works that positioned to 6th and 7th, respectively within the overall problems and considered as key socio-economic problem. Industrial effluent also leads to deterioration of air, water and soil quality, which ranked 1st within the both health and environment- and cumulative-problems with the total score of 147. Since the abiotic resources, including soil, air and water become contaminated by industrial effluent; therefore, migration of animal species increased remarkably, which positioned 2nd within the health and environment-problems.

Proportionate reduction of heavy metal accumulation was observed with the increase of distance from the source of contamination. For both water and soils, higher concentrations of Pb (42.11 and 72.63 ppm, respectively), Cd (2.27 and 4.75 ppm, respectively), and Ni (22.25 and 61.50 ppm, respectively) were observed in less than 10 m distance followed by 10-20 m distance from the contaminated-industrial source. Meanwhile, the lower concentrations of Pb (31.95 and 33.95 ppm), Cd (0.75 and 1.41 ppm) and Ni (14.25 and 22.00 ppm) were found at >40 m distance from the industry in both water and soils, respectively.

CONCLUSION

Variations in soil pollution and fertilizer treatments had significant influence on the yield and yield-contributing attributes of boro rice and showed almost similar trend of results. More specifically, the higher values of the yields and yield-contributing attributes were documented in T_2S_1 (non-polluted soil and 50% RDCF + 6 ton cowdung ha^{-1}) treatment combination followed by the treatment combination of T_1S_1 (non-polluted soil and 100% RDCF), whereas, the lower values of those respective parameters were recorded in T_0S_3 (polluted soil 2 and control) treatment combination.

Corresponding to the results of the yield and yield-contributing attributes of boro rice, the similar responses of all the above-mentioned studied parameters for T. Aman rice were also found in T_2S_1 treatment combination followed by T_1S_1 treatment combination, while the abated values were recorded in T_0S_3 treatment combination.

Intriguingly, maximum Cd accumulation in the rice grains of both boro and T. Aman was reported to be found in the treatment combination of T_1S_3 (polluted soil 2 and 100% RDCF), however, Pb content in T. Aman rice grains also showed the similar results, i.e. maximum in T_1S_3 treatment combination. Zn accumulation in boro and T. Aman rice grains was reported to found higher in T_1S_3 treatment combination. Nonetheless, lower accumulation of those above-mentioned metals in both varieties of rice grains were documented in T_0S_1 (non-polluted soil and control) treatment combination.

Minerals as well as heavy metals content in soils act as a key reservoir to transfer those to the above-ground parts (grain). Different properties of soils, including pH, percentage of OM, K, P, S, Zn, Cu, Mn, Fe, Ca and Mg were found in higher levels in the treatment combination of S_1T_2, whereas, the lower values of those above-mentioned parameters were documented in T_0S_3 treatment combination, except K (found lower in T_1S_3 treatment combination). On the other hand, indispensable mineral, including N was stated to be found greater in T_1S_1 treatment combination, whereas lowest value was noted in several treatment combinations, including T_0S_3, T_1S_3 and T_2S_3. In case of heavy metals like Zn, Cd, Pb, Cr and Ni, their augmented values were recorded in T_1S_3 treatment combinations, whereas their lowest values were embossed in T_0S_1 treatment combination.

Different gradients of fertilizers as well as irrigation practices significantly influenced the yield and yield-related-attributes of boro rice. However, the yield-contributing features, including plant height, total number of effective tillers per hill number of effective tillers per hill, length of panicle, filled and unfilled grains per panicle, thousand-grain weight, grain and straw yields were found higher in the treatment combination of T_4I_1 (50% RDCF + 5 ton compost ha^{-1} and traditional irrigation) followed by T_3I_1 (50% RDCF + 6 ton cowdung $^{-1}$ and traditional irrigation) treatment combination. In contrast, the lower values of those respective parameters were noted in T_0I_2 (control and alternate wetting drying) treatment combination followed by T_1I_2 (100% RDCF and alternate wetting drying) treatment combination.

The yield and yield-associated-attributes of T. Aman rice were also influenced significantly when exposed to different treatments of fertilizers as well as irrigation methods. Likewise, the outcomes of the above-mentioned parameters of boro rice, utmost values of those respective parameters for T. Aman rice were also found maximum in T_4I_1 treatment combination, followed by T_3I_1, whereas, the abated values were inscribed in T_0I_2 treatment combination, which was followed by T_1I_2 treatment combination. Nevertheless, numerically the highest and lowest values of thousand grains weight were registered in T_4I_1 and T_0I_2 treatment combinations, respectively.

The accumulations of heavy metals in rice grain grown in arsenic contaminated soils were differed significantly with the divergence of fertilizers and irrigation types. The higher accumulation of toxic metals, including Cd and Zn in both boro and T. Aman rice, As in boro rice, and Pb in T. Aman rice grains were recorded in T_2I_2 ($N_{150}P_{60}K_{60}S_{20}Zn_{3.0}$ and alternate wetting drying) treatment combination, whereas the abated values of those respective parameters were registered in T_0I_1 treatment combination.

The properties of soils showed significant changes in response to variation of fertilizers and irrigations types. The higher values of the soil properties, including- pH, OM percentage, K, N, P and S were found in T_4I_1 treatment combination, whereas, the lower values of those respective parameters were recorded in T_0I_2 treatment combination, except N (found lower in T_0I_2, T_1I_2, T_2I_2, T_3I_2 and T_4I_2 treatment combinations).

Most of the surveyed respondents were literally uneducated and belonged to middle aged as well as medium sized family. With aim to supplement the family income, especially the respondents have small sized farm were also engaged in different occupation, including driving, fishing, business and day laboring apart from farming as a key profession. Predominantly, industrial effluent contamination severely hampered the rice production in several ways, including abating fertility, augmenting production cost, quality and yield deterioration, which lead to fall in market price and our surveyed respondents were also agreed to those problems and even some were strongly agreed. Industrial effluent not only restrained rice production, rather it deteriorates the color and odor of the adjacent soils, which is also conferred by the respondent’s opinions that after establishment of industry soil quality deteriorating day by day. Respondents also opined that they use surface water in the recent past for drinking, cooking, domestic usage, irrigation and bathing, however, after unplanned industrial exploration the color and odor of the surface water become bad to very bad and untenable for daily usage. Interestingly, respondents opined that the quality of ground water in terms of color and odor was not so worst (mostly rated as very good to good) like surface water, even after industrial inauguration, and they can use it comfortably as the above-mentioned activities of surface water. However, respondents told that when they grow rice in industrial effluent contaminated area, severe yield reduction was experienced for boro rice, while medium for aus rice; interestingly, low yield reduction was noticed for the case of Aman rice. Although they said that the grain size, shape and color were not distorted significantly due to industrial effluent contamination, but the taste and odor of the rice grain become unpleasant, which lead to lower market price that makes the respondents towards demotivation of rice cultivation in effluent-contaminated area. Nevertheless, industrial effluents are directly or indirectly responsible for causing a number of productions, socioeconomic, and health and environment-related problems. Total of sixteen prime problems, respondents prioritized the gradual deterioration of air, water and soil quality belongs to health and environment associated problems followed by production-oriented problems, namely reduction of soil fertility, higher input cost and lower yield. However, lower income and shifting primary occupation was the moderate gradient problems belongs to socio-economic-oriented problem. Distance from the source of industries act as a major influential factor of heavy metals accumulations in both soil and water, and it is presuming that heavy metal accumulation decreases concomitantly with increasing distances from the industrial point, which also manifested in our present study by the respondent’s opinions.

CHAPTER VI

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CHAPTER VII

APPENDIX

Farmers' Perceptions on Impact of Industrial Effluent Contamination on Rice Production

Sl. No: _ _ _ Date: _ _ _ _ _ _ _ _
Name of the respondent: _ _ _ _ _ _ _ _ _ _ _ _ Mobile No: _ _ _ _ _ _ _ _ _ _ _ _
Village: _ _ _ _ _ _ _ _ Union: _ _ _ _ _ _

Please answer the following questions and put tick (√) mark whenever necessary

1. Age: _ _ _ _ _ _ (years)

2. Level of literacy

☐ No education	☐ Can sign only		☐ Primary (up to 5 class)
☐ Secondary (6 to 10 class)	☐ S.S.C.	☐ H.S.C.	☐ Above H.S.C.

3. Please mention the numbers of your family members including you

Male =	**Female =**	**Total =**

4. Types of family where respondent stay

a) Nuclear family b) Joint family

5. How long have you have been here?

a. From after birth _ _ _ _

b. Years _ _ _ _

6. Occupation

Primary occupation	**Secondary occupation**
1. Farming _____	1. Driving_____ 2. Fishing_____ 3. Business____ 4. Boatman_____ 5. Others______

7. Farm size (ha) ___________

Please indicate the area of land in your profession

Sl No	Type of land use	Land area	
		Local unit	Hectare
1	Homestead area		
2	Land under own cultivation		
3	Land shared in		
4	Land shared out		
5	Land taken from others on lease		

8. Annual family income

Please indicate the income your family obtained from the following activities during the last year

Sl No.	Source of income	Total (TK.)
A	**Farm**	
1	Rice	
2	Vegetables	
3	Fruits	
4	Fish culture	
5	Poultry	
6	Cattle rearing	
B	**Non-Farm**	
1	Small business	
2	Labour	
3	Others (if any)	

Total income (A+B)

9. Farmers' perceptions on impact of industrial effluent contamination in rice production

Sl. No	Perception statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1	Industrial effluent reduced fertility of rice field					
2	Industrial effluent contamination increase cost of rice production					
3	Rice quality declined than before as a result of effluent					
4	Yield of rice reduced due to effluent contamination					

5	Price of rice declined because of decreased face value					
6	Using effluent contaminated water as irrigation is not much harmful					
7	Water contamination increased after establishment of industries					
8	Situation is becoming unfavorable day-by-day					
9	As contamination increased people aren’t interested in rice production like before					
10	Information and awareness about impact of effluent contamination is inadequate					

10. Soil quality

Please mention the quality of soil before and after the establishment of industries in your locality.

Types of land	**Before establishment of industry**		**After establishment of industry**	
	Color	**Odor**	**Color**	**Odor**
High land				
Medium land				
Low land				

11. Water quality

Please mention the quality of water before and after the establishment of industries in your locality.

Types of water	**Uses of water**	**Before establishment of industry**		**After establishment of industry**	
		Color	**Odor**	**Color**	**Odor**
Surface water	1.Drinking				
	2.Cooking				
	3.Domestic activity				
	4.Irrigation				
	5.Bathing				
	6. Animal Bathing				
	7.Boating				
Ground water	1.Drinking				
	2.Cooking				
	3.Domestic activity				
	4.Irrigation				
	5.Bathing				
	6. Animal Bathing				

12. Different species status

Please mention the extent of different animal and plant species before and after the establishment of industry in your locality.

Species	**Before establishment of industry**	**After establishment of industry**
Fish		
Shellfish		
Aquatic plants		
Birds		
Reptiles		
Insect infestation		
Natural enemies		

13. Yield of crop

Please mention the yield of different crops during pre and post establishment of industry in your locality.

Types of Rice	**Categories of Decrease**
Aus	
Aman	
Boro	

14. Quality of Rice

Please mention the quality of food crops before and after the establishment of industry in your locality.

Types of Rice	Before establishment of industry					After establishment of industry				
	Size and Shape	Taste	Color	Odor	Market Value	Size and shape	Taste	Color	Odor	Market Value
Rice										

15. Problems of industrial effluent contamination

Please indicate the extent of your confrontation with the following problems in your locality due to industrial effluents

Sl. #	**Problem Statements**	**Extent of opinion**		
		Low	**Medium**	**High**
Production related				
1	Low soil fertility in rice field			
2	High input cost			
3	Low yield			
4	Increase attack of insect			
5	Deformed shape of grain			
6	Bad smell and taste			

7	Low market price			
Socioeconomic related				
8	Low income			
9	Loss of land			
10	Shifting to other occupations			
11	Social conflict			
12	Food crisis			
Health and Environment related				
13	Dermal disease			
14	Respiratory disease			
15	Polluted air, water and soil			
16	Migration of different animal sp.			

16. **Please suggest some solution of the aforesaid problems caused due to industrial effluents.**

a)
b)
c)

Thank you for your nice cooperation

____

Signature Date: