TOXICITY OF HEAVY METALS IN SOILS AND CROPS AND ITS PHYTO-REMEDIATION

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Abstract

Soils, water and crops contaminated by heavy metals and other environmental toxins from different industrial wastes and wastewaters in and around Dhaka are producing unhealthy food through entering into the food chain, which is consumed by human beings. The present study has been undertaken to evaluate the amount and extent of pollution of the wastewaters, soils and crops and their phyto-remediation potentials. So, the study was conducted in two stages: field survey and green house study. In field study, ten industrial clusters at different locations in and around Dhaka were selected and their wastewaters, soils and plant samples were collected and analysed for the level of contamination. Parameters considered to study for wastewaters- pH, EC, Conductivity, TDS, Turbidity, DO, NO_2^- -N, NO_3^- -N, NH_4^+ -N, SO_4^{2-}, total alkalinity, PO_4^{3-}, Cl^-, Na, K, Ca, Mg, Zn, Cu, Ni, Pb and Cd; for soils- pH, EC, OC, TN, TP, Na, K, Ca, Mg, Zn, Cu, Ni, Pb and Cd; for crops- N, P, K, Na, Ca, Mg, Zn, Cu, Ni, Pb and Cd. In green house study, for the phyto-remediation of heavy metals, pot experiments were conducted to evaluate the toxicity levels of Pb and Cd in soils and crops by using Brridhan- 28 rice as a test crop and to determine the tolerance potentials of five common high yielding rice varieties such as BR- 15, BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45 by applying 200 mg/kg Pb and 7 mg/kg Cd separately, as well as to assess the phyto-extraction and tolerance potentials of Lal sak, Kalmi sak, Grass and Spinach by applying 200 mg/kg Pb and 15 mg/kg Cd alone.

After analysing the wastewater samples of different industries in and around Dhaka, some polluting industries were identified. Among them the worse industries were tanneries at Hazaribagh. Because, EC, conductivity, TDS, NO_2^- -N, NO_3^- -N, NH_4^+-N, SO_4^{2-}, PO_4^{3-}, Cl^-, Na, K, Ca, Mg and Cd concentration in the wastewaters at Hazaribagh tannery area was found very high. On the other hand, DO of the wastewaters at tannery industries were found the lowest, with the highest turbidity. But, pH of the wastewaters near I I Tubes Mills Ltd. at Demra- 3 was found extremely acidic with substantial amounts of NO_3^- -N, NH_4^+ -N and Zn. And lead-storage battery industries at Keranigonj- 3 contributed extremely acidic pH value, huge amounts of sulphates and toxic concentrations of Zn, Cu, Ni and Pb to the wastewaters. pH and total alkalinity in the wastewaters at Gazipur- 5 near Haq battery was found high. Pb, Ni and K concentration was also found above the tolerable limit. On the other hand, Ca, Mg, Zn, Cu and Cd concentrations near textile dyeing, spinning and tannery industries were found high as well.

pH of the soils at Keranigonj- 3 near lead-storage battery industry and Demra- 3 near I I tube Mills Ltd. was found extremely acidic and near dyeing industries at Matuail- 2 and Shampur- 2, it was found alkaline. Organic carbon, Total N and Total P contents at Hazaribagh and Tejgaon areas were found higher as compared to other industrial sites. Na and K concentrations in soils at Hazaribagh tannery areas was found high, while at Gazipur- 5 near Haq battery, K concentration was found substantially high. Ca and Mg concentrations near textile dyeing industries and metal industries were found substantially high as well.

Likewise, Zn, Cu, Ni and Pb concentration in the soils near electroplating, galvanizing, storage and dry cell batteries, metal processing products, steel and rerolling, tannery and textile dyeing industries were found high. An exceptionally high Pb concentration was found at Keranigonj- 3 near lead-storage battery industry, Cu was found at Demra- 4 near Alaksa Steel Mills Ltd., Ni near Metrocem Ispat Ltd. at Gazipur- 4 and Zn at Demra- 3 near I I Tube Mills Ltd. In contrast, textile dyeing and tannery industries contributed high Cd at different locations, and remarkably high concentration of Cd was found at Hotapara near dyeing and at Hazaribagh near tannery industries. In most crops, Zn and Cu concentrations were found above the phyto-toxic limit, while Ni, Pb and Cd contents were found below the phyto-toxic limit but above the tolerable range for human consumption.

In green house study, the effect of Pb on the growth and yield of Brridhan- 28 rice had been initiated significantly at T2 treatment, where 125 mg/kg Pb was applied over control. And, the significant effect of Pb on the nutrient contents such as N, P, K, Ca and Mg in Brridhan- 28 rice was commenced at T1 and T2 treatments, where 100 mg/kg and 125 mg/kg Pb was applied as compared with control. On the other hand, the growth, yield and mineral nutrition of Brridhan- 28 rice had been significantly affected at 3 mg/kg Cd treatments and upwards over control and at 60 mg/kg and 90 mg/kg Cd treatments, Brridhan- 28 rice crops could not grow at all. A significant increment of Pb and Cd concentrations was found in grains, straw and roots of Brridhan- 28 with increasing metal treatments and simultaneously their growth and yields had been hampered. In phyto-remediation studies, among the five rice varieties BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45 were found as 200 mg/kg Pb tolerant and BR- 15, BR- 19, Brridhan- 29 and Brridhan- 45 were identified as 7 mg/kg Cd stress tolerant as they showed better growth performance with minor quantities of Pb and Cd in grains. On the other hand, metal concentrations in the straw were found within the toxic range, while roots of those rice varieties sequestered maximum amounts of Pb and Cd and acted as metal sequester. In contrast, Brridhan- 15 was observed as Pb and Brridhan- 16 was found as Cd susceptible varieties as their growth and yield had been significantly affected and metal transportation in straw and grains from roots were increased.

Among the leafy vegetables and grass, the growth and yield of spinach had been significantly affected by 200 mg/kg Pb and 15 mg/kg Cd application. The growth of Lal sak had been drastically affected by 15 mg/kg Cd as well, but remained unaffected by 200 mg/kg Pb treatment over control. Conversely, the growth of Kalmi sak and Grass had not been affected significantly by 200 mg/kg Pb and 15 mg/kg Cd treatments over control. But, Lal sak, Kalmi sak and Spinach accrued high Pb and Cd in their straw and roots as hyper accumulating plants, whereas grass accumulated the lowest quantities of Pb and Cd as metal excluder and/or metal phyto-stabilizer. Metal concentration in different parts of crops exhibited the following descending order: Roots> Straw> Grains. The transfer co-efficients of metals varied in a wide range among different crops and cultivars.

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1. INTRODUCTION

1.1 *Rationale*

Industrial revolution and modern civilization have turned the soil, air, water and livelihood into the wastebasket where dusts, noxious fumes, toxic gases, mists, metals, odor, and smoke are thrown. Heavy metals (HMs) are among the major environmental contaminants and pose a threat to human and animal health. It differs from air pollution, because heavy metals persist in soil much longer than in other compartments of the biosphere (Lasat, 2002; Gisbert *et al*., 2003; Halim *et al*., 2003; Zeng *et al*., 2010). And, the toxicity of heavy metals is a function of its solubility and has no biological role in plants (Web. 1). In fact, heavy metal pollution now a day is an ever-increasing world-wide issue (Kashem and Singh, 1998; Jamali *et al*., 2007).

Soil and water are precious natural resources and the primary recipient of heavy metals on which the sustainability of agriculture and the civilization of mankind depend. But, environmental pollution affects the quality of lithosphere, hydrosphere, atmosphere and biosphere (Lone *et al*., 2008). Heavy metal concentrations in soils, crops and water are associated with biological and geochemical cycles and are influenced by anthropogenic sources such as pesticide and fertilizer use, solid waste and sludge disposal, dyeing, textile, tanneries, processes including electroplating, batteries, wielding, metalliferous mining and smelting, metallurgical industries, sewage sludge treatment, warfare and military training, electronic industries and pigments (Alloway, 1995; Lugon-Moulin *et al*., 2006; Ewah *et al*., 2009; Sharma *et al*., 2009). They pollute soils and natural water systems as well as ground water, and they tend to persist indefinitely, circulating and eventually accumulating throughout the ecosystem. And thereby, create serious environmental hazards, endanger human health and cause problems to aquatic lives. Some of the heavy metals are phyto-toxic and some are toxic to both plants and animals through their entry into the water-soil-plant-food system (Islam *et al*., 2002).

Random disposal of industrial wastes onto the nearby lands and the use of industrial effluent and sewage sludge on agricultural land has become a common practice in the world as a result these toxic metals can be transferred and concentrated into plant tissues from the soil. This issue is highly addressed in both developing and developed countries today (Ghani, 2010). It is a great challenge in China, where one-sixth of the total arable land has been polluted by heavy metals and more than 40% has been degraded in varying degrees due to erosion and desertification (Liu, 2006). On the other hand, in western Europe, 1,400,000 sites were affected by heavy metals (McGrath *et al*., 2001), of which over 300,000 were contaminated, and the estimated total number in Europe could be much larger, as pollution problems increasingly occurred in central and eastern European countries (Gade, 2000). And, in USA, there are 60,000 brown fields which are contaminated with heavy metals and needed reclamation (McKeehan, 2000). Soil and water pollution is also severe in India and Pakistan,

where small industrial units are pouring their untreated effluents in the surface drains, which spread over near agricultural fields. In India, Sharma *et al.* (2009) revealed that the industries discharge waste and effluents containing toxic heavy metals such as copper, nickel, zinc, lead, arsenic, cadmium and chromium which ultimately accumulated in soils and plants in variable quantities. The presence of any metal may vary from site to site depending on sources.

Wastewaters are being used for irrigation and uninterrupted application of industrial wastewaters for irrigation over the past few decades has led to the accumulation of heavy metals (Helal *et al.*, 1998) and toxic chemicals in upper soil strata and also surface water in many countries as well. And, the lack of clean water has always been an issue of environmental concern all over the world. The main sources of water pollution are: industrial (chemical, organic and thermal wastes), municipal (largely sewage consisting of human wastes, other organic wastes and detergents) and agricultural (animal wastes, pesticides and fertilizers) (Brower *et al.*, 1990). All countries have been affected through water pollution by heavy metals, though the area and severity of pollution vary enormously (Liu, 2006).

In Bangladesh, pollution control issues are relatively recent. With few exceptions (only 1.75%), the industries are not well equipped with pollution control systems (DoE, 1992). The rivers around the industrial belts of Dhaka, Narayangonj, Chittagong and Khulna are major receiver of the untreated effluents coming from tanneries, textiles, chemicals, pesticides, medicines, foods, engineering etc. (Imamul Haq, 1998). And, about 40,000 tones of wastes from about 1000 small and large industries are being dumped into the river system from Dhaka Metropolitan area (Rao and Rao, 1993 and Masters, 1995). According to statistics of DoE, the number of polluting dyeing mills are 365, tanneries 198, pharmaceutical units 149, engineering workshops 129, chemicals and pesticide factories 118, jute mills 92, rubber and plastic units 63, food and sugar 38, paper and pulp 10, cement and fertilizers five each and distilleries 4 in Bangladesh (Roy, 2009); but around 350 dyeing, tannery, chemicals, paper and food processing and other industries are polluting the water in Bangladesh severely (Roy, 2009). Ullah *et al.* (1995) stated that there were about 30,000 big and small industries situated in Dhaka city. And, the effluents discharged from those industries into the drains, rivers, ponds, lakes and lagoons that contained metals like Fe, Mn, Zn, Cu, Cr, Ni, Cd and Pb along with some sodium phosphate, nitrates, nitrites, sulphate etc. and are affecting the natural water quality of Dhaka city. On the other hand, Nuruzzaman (1995) and Kashem and Singh (1998) reported that tannery, textile, dyeing, battery and sulphuric acid producing industries etc. increased the concentration of Cu, Mn, Ni, Pb, Cr, Zn etc. up to toxic levels and somewhere exceeded the toxic limit in the soils and crops near different industrial sites in and around Dhaka.

Excessive uptake of metals by plants may create a range of agricultural and human health-related hazards (Trivedi and Erdei, 1992; Kumar *et al.*, 2009). Metabolic pathways during the

growth and development of plants such as photosynthesis (Bercerril *et al.*, 1988), respiration, carbohydrate metabolism (Greger and Lindberg, 1986), water relations and uptake and distribution of essential mineral nutrients in plants (Breckie and Kahle, 1992), biomass production (Purves, 1985) etc. are affected to a serious extent and cause degeneration of main cell organelles, even leading to death of plants (Garbisu and Alkorta, 2001; Schmidt, 2003; Schwartz *et al.*, 2003) and itai itai, kidney and liver malfunctioning, cancer etc. in human. Soil contamination with heavy metals may also cause changes in composition of soil microbial community, adversely affecting soil characteristics (Giller *et al.*, 1998; Kozdrój and Van Elsas, 2001; Kurek and Bollag, 2004). The presence of heavy metals in soils and their solubility in soils and uptake by plants depend on several factors such as pH, redox-reaction, organic matter status, phosphates, carbonates etc. and the kinds of metals and species of crop varieties. Differences existed among the cultivars for the uptake and distribution of heavy metals in plants, but the differences were not necessarily related to genotype. The coexistence of essential and non-essential elements in the ecosystem leads to interactions that may be additive, antagonistic or synergistic (Siedlecka, 1995).

Among the heavy metals, Cd and Pb are considered as ruthless environmental hazards because they are toxic to human and other organisms (Wang *et al.*, 2006; Ekmekyapar *et al.*, 2012; Ghaderi *et al.*, 2012). On the other hand, an increasing number of paddy fields in many Asian countries have been reported to be contaminated by toxic elements including cadmium (Cd) and lead (Pb) which is largely due to anthropogenic activities (Rogan *et al.*, 2009; Williams *et al.*, 2009). Although Cd and Pb are not necessary elements for plants, the plants absorb these elements from soil and concentrate them in different edible organs. These elements are not only toxic to human, but their concentration and absorption in plant organ cause rigorous toxicity (Florijn and Van Beusichem, 1993 and Li *et al.*, 1995). Kuzovkina *et al.* (2004) mentioned that Cd could be strongly phyto-toxic causing rapid death of plants. Large quantities of fertilizers are regularly added to soils during intensive farming systems which provide adequate N, P and K for crop growth; but the fertilizers used to supply these elements contain trace amounts of heavy metals (e.g., Cd and Pb) as impurities, which after continued application may significantly increase their content in the soil (Jones and Jarvis, 1981; Ravan *et al.*, 1998).

Soils have a natural capacity to attenuate the bioavailability and movement of heavy metals through them by means of different mechanisms such as precipitation, adsorption process and redox-reactions. But, if the concentration of heavy metals becomes too high to allow the soils to limit their potential effects, the metals can be mobilized resulting in serious contamination of agricultural products and the environment (Hseu *et al.*, 2010). So, in order to maintain good quality of soils and water and to keep them free from contamination, continuous efforts have been made to develop technologies that are easy to use, sustainable and economically feasible. The remediation technologies applied on soils contaminated with heavy metal include physical, chemical and biological methods, but these methods have their drawbacks

in effectiveness, duration and economics (Iskandar and Adriano, 1997; Zaurov *et al*., 1999). Among the methods, the physico-chemical approach includes excavation and burial of the soil at a hazardous waste site, fixation/inactivation, leaching by using acid solution (Salt *et al*., 1995), precipitation or flocculation followed by sedimentation, ion exchange, reverse osmosis and microfiltration (Raskin *et al*., 1996). The physico-chemical approaches have been widely used to remediate polluted soils and water, especially at a small scale but they are costly and have side effects (Raskin *et al*., 1997; McGrath *et al*., 2001; Lasat, 2002).

Over the last few decades, a fast emerging, low-cost and eco-friendly alternative to the conventional remediation techniques has gained ground both in public and private sectors termed as "Phyto-remediation". This technique engages plants to cleanse the nature, as plants can absorb, accumulate and detoxify contaminants of their substrates (soil, water and air) through physical, chemical and biological processes (Lasat, 2002) and it is also referred to as botanical bioremediation (Chaney *et al*., 1997), which involves the use of green plants to decontaminate soils, water and air. It can be applied to both organic and inorganic pollutants present in the soil, water or air (Salt *et al*., 1998). It is also innovated that some selected plant species possess the genetic potential to remove, degrade, metabolize or immobilize a wide range of contaminants. Despite this tremendous potential, phyto-remediation is yet to become a commercial technology (Lasat, 2002). Phyto-remediation, being more cost effective and fewer side effects than physical and chemical approaches, has gained increasing popularity in both academic and practical circles (Lone *et al*., 2008).

The efficiency of phyto-remediation depends on the soil and plant factors, such as, the physical and chemical properties of the soil, the plant and microbial exudates, bioavailability of metals, and the ability of plants to uptake, accumulate, translocation, sequester and detoxify metals (Hooda, 2007). Some species of higher plants can accumulate very high concentration of metals in their tissues (Klassen *et al*., 2000 ; Bennet *et al*., 2003) and some plant cultivars reduce leaching, runoff of roots and via root exudates may cause metal to precipitate, converting them to less bio-available form (Berti, 2000). On the other hand, some plants take up contaminants from the soil and transform them in volatile form and transpire them into atmosphere (USPA, 2000) and some of the plants extract heavy metals from rhizosphere and sequester or sink them into roots and resists them from transfer to the upper portion of the plants. It takes advantage of the unique, selective and naturally occurring uptake capabilities of plant root systems, together with the translocation, bioaccumulation and pollutant storage/degradation abilities of the entire plant body. Besides, being aesthetically pleasing, phyto-remediation is on average ten-fold cheaper than other physical chemical or thermal remediation methods.

Phyto-remediation technologies are now a day increasingly used to remediate the metal contaminated soils. In some countries, it has focused on the use of plants as bio-pumps (Robinson *et al*., 2003) to reduce contaminants mobility and to degrade organic pollutants,

rather than the phyto-extraction of heavy metals (Hamblin, 2001). But, some researchers of India emphasized particularly on phyto-extraction for the decontamination of soil heavy metals (Ghosh and Singh, 2005). They also gave attention on the weed crops with high biomass to restrict the passage of contaminants into the food chain by selecting non-edible disease resistant and tolerant plants, which could provide renewable energy. Conversely, for the remediation of polluted industrial and sewage water, long and extensive root system plants have been considered by Luqman *et al*. (2013) of Pakistan. In Bangladesh, Imamul Haq *et al*. (2005) had tried to remediate arsenic contaminated soil by using Marigold (*Tagetes patula*) and ornamental arum (*Syngonia* sp.) and they considered them as a good phyto-extractants. On the other hand, Shams *et al*. (2008) observed that *Urtica dioica* was the most potential plant to phyto-extraction and remove Cr from contaminated sites. However, the data regarding the phyto-remediation study in Bangladesh is scanty.

1.2 *Objectives of the study*

Keeping all the above views in mind, the present piece of research work has been designed and undertaken with the following objectives-

1. To evaluate the physico-chemical features and heavy metals such as Zn, Cu, Ni, Pb and Cd concentration in the wastewaters collected from different industrial clusters in and around Dhaka.

2. To determine the properties and heavy metals status as mentioned above in the polluted soils collected from different industrial clusters in and around Dhaka.

3. To measure the toxic concentration of those heavy metals in the contaminated crops collected from different industrially polluted lands in and around Dhaka.

4. To assess the effects and toxicity levels of Pb and Cd on a rice variety as a test crop.

5. To investigate the phyto-remediation possibilities of Pb and Cd with five common rice cultivars of Bangladesh.

6. To study the phyto-remediation potentials of Pb and Cd with three common leafy vegetable crops and a grass crop.

2. REVIEW OF LITERATURE

The wastes and wastewaters generated by different kinds of industries and its indiscriminate discharge into natural systems is a concerning issue all over the world. The wastes and effluents contain varying amounts of different environmental toxins and heavy metals such as Cu, Ni, Zn, Pb, Cd, Hg etc. They are thereby creating severe impact on the quality water and contaminating soils and crops of that area as well. In Bangladesh, industrial wastes and effluents are being randomly discharged without treatment into the natural systems and creating serious environmental hazards. But, the data regarding the extent of hazard is scarce. So, this chapter includes the sources, characteristics, evaluation and scenarios of industrial wastes and effluents, sources and toxic effects of heavy metals on soils and crops and their possible remediation techniques.

2.1 *Wastes and Effluents*

Public Advisory Panel of Chemical Manufacturing Association U.S.A. defined waste as "any gas, liquid or solid residual material at a facility, whether hazardous or non hazardous, that is not used further in the production of commercial product or provisions of a service and which itself is not a commercial product" (BCAS, 2001). And effluents are wastewaters originating from community, agricultural operations and different industries. Alam (2003) reported that due to the lack of consciousness, industrial wastes and effluents are being randomly discharged into the ponds, lagoons, ditches as an easy way to drain effluents (both solid waste and wastewaters) without any consideration of environmental degradation.

The most common kinds of waste can be classified into four types: agricultural, industrial, municipal and nuclear (Alloway, 1995). Peavy *et al.* (1985) classified wastes as municipal, industrial and hazardous. And industrial wastes arising from industrial activities and typically include rubbish, ashes, demolition, and construction wastes, special wastes and hazardous wastes. Hazardous wastes pose a substantial danger immediately or over a period of time to human, plant, or animal life, which exhibits ignitibility, corrosivity, reactivity or toxicity (Peavy *et al.*, 1985). The wastes and effluents contained several kinds of toxic chemicals and heavy metals. Duval *et al.* (1980) reported that effluents derived from tannery contains excess fat, hair, grease, sulphides, sulphates, caustic soda, calcium hydroxide, chloride, sulfuric acid, chromium, oils, dyes and varying amounts of heavy metals such as Zn, Cu, Ni, Pb, Cd and Cr.

Heavy metals such as lead (Pb), chromium (Cr), cadmium (Cd) and copper (Cu) are widely used for production of color pigments of textile dyes (Halimoon and Yin, 2010). According to AEPA (1998), textile dyes and pigments had contributed to overall toxicity at all stages such as high level of BOD/COD, colors, surfactants, fibers, turbidity, trace metals (Cd, Cr, Cu, Pb, Hg, Se, Zn, Co, Mn, Ni, As etc.), suspended solids, nitrogen, phosphate, pH,

alkalinity-acidity, oil and grease, sulphides and coliform bacteria. Some characteristics of effluents of different kinds of industries are presented in Table- 2.1.

Table- 2.1: Characteristics of industrial effluents derived from different kinds of industries

Selected parameters (mg/L)	Textile effluents	Tannery effluents	Pulp and paper industries	Effluent standard (GoB, 1997)
BOD,	81,00	36,000	600	50
COD	17,100	56,400	1,700.	200
Suspended solid	15,221	7,498	2,024	150
Nitrate	200	700	-	10
Chloride	80,000	62,500	5,900	600
Chromium	0.47	3,818	-	0.5
Sulfide	-	1,500	-	1.0

(Source: Rahman, 1997)

Foess and Ericson (1980) reported that most pharmaceutical effluents contained varying concentration of organic compounds and total solids, heavy metals such as Pb, Hg, Cd, Ni, Cr and other toxic organic chemicals or phenolic compounds. Trace constituents of many metals such as Cr, Pb, Ni, and Zn are important constituents of effluents. Main sources of those metals are mining activities, foundries, smelting such as piping, constituents of products, combustion byproducts, traffic and vehicles.

2.1.1 *Industrial, Municipal and Urban Wastes in Bangladesh*

The earliest industries in Bangladesh were based primarily on agricultural products like jute, sugarcane, tobacco, forest raw materials, and skins. During the mid-sixties a modern industrial base emerged as heavy industries like steel, machine tools, electric machines, diesel plants, refineries, pharmaceutical plants and other chemical industries were set up. The concentrations of DDT, PCBs, industrial solvents and other toxic chemicals, which originate primarily from mining, oil refineries, chemical works and in textile, wood pulp, and pesticide factories are also rising.

In recent years, the major source of industrial growth has been in textiles with ready-made garments manufacture expanding from insignificance in the 1970s to the leading export earner today. Leather tanning and brackish water shrimp farming have also been expanded rapidly and are expected to grow further. The industrial areas in Bangladesh are situated in the middle of densely populated regions. There are many hazardous and potentially dangerous polluting industries situated in the cities of Bangladesh. And, Surface water pollution is an alarming issue in Bangladesh and it occurs mainly due to human sewage coupled with municipal garbage and industrial effluents. Industrial discharges along with municipal and urban wastes are creating special problems that completely destroy the

microbial-based systems of decomposition. About 6,000 large and medium industries and 24,000 small industries are operating in Bangladesh, which discharge effluents directly to the rivers or nearby canal or waterbed without any regard to environment. According to the Department of Environment, the Government of Bangladesh, about 878 industries (Table-2.2) are the most polluted industries of Bangladesh. But there is no monitoring facility for controlling or inventorying on water qualities of rivers of Bangladesh (DoE, 2003).

Table- 2.2: Number of Different Categories of Polluting Industries in Bangladesh

Category of industry	Number
Tanneries	176
Paper and pulp plants	5
Sugar mills	16
Distilleries	3
Iron and steel mills	57
Textile units	298
Fertilizer plants	5
Insecticide industries	23
Jute industries	92
Cement industries	3
Rubber and plastic industries	34
Pharmaceutical industries	166
Total	878

(Source: DOE, 2003)

2.1.2 *Scenarios of Industrial Wastes and effluents in and Around Dhaka*

Dhaka is the capital city of Bangladesh and over the last 10 years, major industrialization has been observed in the Dhaka watershed, especially in dyeing, washing and textile sectors. And it is estimated that there are over 7000 industries in Dhaka metropolis located mostly in three clusters: Hazaribagh, Tejgaon and DND area (Roy, 2009). According to a study jointly conducted by the World Bank and the Institute of Water Modeling (IWM), there are over 300 various effluent discharge outlets from nine major industrial clusters including Tongi, Hazaribagh, Tejgaon, Tarabo, Narayanganj, Savar, Ashulia, Gazipur and Ghorasal. Of these, 19 outlets carry the major discharge of domestic and industrial waste. Of the discharged untreated liquid waste, 61 percent are industrial and 39 percent domestic waste (Roy, 2009).

In Dhaka, the tannery industries at Hazaribagh area discharge their wastewater into the Buriganga River through three outfalls. Further downstream, the Fatullah (Narayangonj) industrial area (mainly textiles and steel re-rolling industries) drains its wastewater partly via the lowland of the same river. The Tongi industrial area (mainly textiles and re-rolling industries) drains its wastewater via a canal to Turag River, which joins the Buriganga in the south. Wastewater from industries in the Tejgaon industrial area (textiles, chemical, paper and steel re-rolling) are discharged in a relatively diffused manner via drains through lowlands, and ultimately into the rivers Buriganga, Turag and Balu. The river Sitalakhya

receives effluents from industries (mainly textiles) located at Tarabo and Kanchpur at Narayangonj (Atiur *et al.*, 2001). Some physical, chemical characteristics and heavy metal concentration in the wastewaters and effluents of Hazaribagh area are presented in Table- 2.3.

Table- 2.3: Some physical and chemical properties and heavy metal concentrations in the wastewater and effluents of Hazaribagh tannery area, Dhaka

Parameters	Wastewater	Effluents
pH	9.90	7.2-12.0
EC(S/cm)	7.40	3.4-20.0 (dS/m)
Cl⁻ (mg/L)	2470.00	1445-18330
PO$_4$$^{3-}$ (mg/L)	30.00	74.00
SO$_4$$^{2-}$ (mg/L)	78-595	250-1040
Phenol (mg/L)	6.92	9.26
Hydrocarbon (mg/L)	0.42	0.22
Fe (mg/L)	0.14	0.05
Mn (mg/L)	0.14	<0.005
Cu (mg/L)	<0.02	0.02
Zn (mg/L)	0.12	0.66-2.40
Cr (mg/L)	0.28	0.34-1.30

(Source: Nuruzzaman *et al.*, 1998)

2.1.3 Some *Physico-Chemical Parameters for Wastewater Quality Evaluation:*

This part deals with the measurement of physical and chemical properties of wastewaters. Many of the determinations included here such as pH, EC, conductivity, TDS, DO, turbidity, sulphate, phosphate etc.

Turbidity: Turbidity in water caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, and plankton and other microscopic organisms (Lenore *et al.*, 1998) and it restricts light penetration in water resulting in reduced primary production i.e., photosynthesis (Gupta, 2001).

pH: Measurement of pH is one of the most important and frequently used tests in water chemistry. Acid-base neutralization, water softening, precipitation, coagulation, disinfection and corrosion in wastewater treatment (Lenore *et al.*, 1998) and activity of organisms, potency of toxic substances in aquatic environment are pH dependent (Rouse, 1979).

Electrical conductivity: But, the electrical conductivity (EC) of water is an indicator of salinity problem. The determination of salt concentration in soils and water is done by measuring electrical conductivity of that soil and water (Michael, 1992).

Total dissolved solids: Total dissolved solids (TDS) comprise of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) and some small amounts of organic matter that are dissolved in water (Gupta, 2001).The variations in the concentration of TDS in river, lagoon or ditch water are due to discharge of effluents and wastes (Moore *et al.*, 1960) from various installations.

Dissolved oxygen: Dissolved oxygen (DO) levels in natural and wastewaters depend on the physical, chemical and biochemical activities in the water body and DO is a key test in water pollution and waste treatment process control (Lenore *et al.*, 1998). Processes in natural waters (Chapman, 1992), without free DO, the river, streams and lake become uninhabitable to gill breathing of aquatic organisms (Vesilind *et al.*, 1990).

Nitrogen (Nitrate, nitrite and ammonium): Nitrogen in wastewaters is found in three different forms such as nitrite, nitrate and ammonium. It is formed in the water of rivers, ponds and streams due to the oxidation or reduction process either by plants, by the action of bacteria or by other organisms. High nitrite concentrations are generally indicative of industrial effluents are often associated with unsatisfactory microbiological quantity of water (Chapman, 1992) and the presence of even minute quantity of nitrite in water is an indicative of organic pollution and prevailing low oxygen concentration. At high concentration, it may cause blue- baby disease (Gupta, 2001). Ammonia is one of the transient constituents in water and is a part of nitrogen cycle and high concentration is toxic to aquatic lives. Nitrate is the highest oxidized form of nitrogen in water; its most important source is biological oxidation of nitrogen. High concentration of nitrate in water is also an indicative of pollution. High nitrate content (>40mg NO_3-N/L) may cause blue-baby disease (Gupta, 2001).

Total hardness: Hardness is caused due to divalent cations such as Ca, Mg, etc. Calcium is the major component of hardness in water and usually in the range between 5 to 500 mg/L as $CaCO_3$ (2 to 200 mg/L as Ca). Higher cations also contribute hardness to a lesser degree but mono-valent cations never produce hardness (Gupta, 2001).

Sulphate: Sulphate (SO_4^{2-}) is widely distributed in nature and may be present in natural waters. Mine drainage wastes may contribute large amounts of SO_4^{2-} through oxidation. Sodium and magnesium sulfate exert a cathartic action (Lenore *et al.*, 1998). The upper limit in portable water is 250 mg/L, based on taste and its potential cathartic effect (Gupta, 2001).

Phosphate: High levels of phosphate may originate from municipal wastewater discharge, since it is an important component of detergents (Chapman, 1992).2.1.4 *Some Cations and Heavy Metals for Wastewater Quality Evaluation*

Sodium: Sodium compounds are used in many applications including caustic soda, salt, fertilizers, and water treatment chemicals. In large concentrations, it may affect persons with cardiac difficulties. The U.S. EPA advisory limit for sodium in drinking water is 20 mg/L (Lenore *et al.*, 1998).

Potassium: Potassium compounds are used in glass, fertilizers, baking powder, soft drinks, explosives, electroplating, and pigments (Lenore *et al.*, 1998). High concentrations may introduce a magnesium deficiency and iron chlorosis in plants (WQA, 2002).

Calcium: Calcium compounds are widely used in pharmaceuticals, photography, lime, deicing-salts, pigments, fertilizers and plasters. Hardness of water is based on the concentration of calcium and magnesium salts, and often is used as a measure of portable water quality. Calcium is necessary in plant and animal nutrition and is an essential component of shell and plant structure (Lenore *et al.*, 1998).

Magnesium: Magnesium is used in alloys, pyrotechnics, flash photography, drying agents, fertilizers, pharmaceuticals, and foods. Among the common aqueous species, Mg^{2+} is important contributors to the hardness of water. Magnesium salts break down when being heated and forming scale in boilers. Some salts of magnesium are toxic by ingestion or inhalation. Concentrations greater than 125 mg/L also can have a cathartic and diuretic effect (Lenore *et al.*, 1998).

Zinc: Zinc is an essential growth element for plants and animals, but at elevated levels it is toxic to some species of aquatic life. The United Nations Food and Agriculture Organization recommended level for zinc in irrigation waters is 2 mg/L. The U.S.EPA secondary drinking water standard MCL is 5 mg/L (Lenore *et al.*, 1998).

Copper: Copper is considered an essential trace element for plants and animals. Some compounds are toxic by ingestion or inhalation. The United Nations Food and Agriculture Organization recommended maximum level for irrigation water is 200µg/L. Under the lead-copper rule, the U. S.EPA drinking water 90th percentile action level is 1.3 mg /L (Lenore *et al.*, 1998).

Cadmium: Cadmium is extremely toxic and accumulates in the kidneys and liver, with prolonged intake at low levels sometimes leading to dysfunction of the kidneys. The United Nation Food and Agriculture Organization recommended maximum level for Cd in irrigation water is 10 µg/L. The U.S EPA primary drinking water standard MCL is 10 µg/L (Lenore *et al.*, 1998).

Lead: Pb is toxic and a cumulative poison. Under the lead-copper rule, the U.S. EPA drinking water 90th percentile action level is 15 µg/L (Lenore *et al.*, 1998).

Nickel: It has a moderate bioaccumulation index in food chain. Ni content in fresh water is 10 µg/L and reference level 0.3 µg/L (Pais and Jones, 2000) and standard for inland surface water is 1.0 mg/L (Chowdury *et al.*, 1999).

2.2 *Heavy Metals: Definition and Major Sources*

A heavy metal is a member of a loosely-defined subset of elements that exhibit metallic properties. It mainly includes the transition metals, some metalloids, lanthanides, and actinides. Many different definitions have been proposed some based on density, some on atomic number or atomic weight, and some on chemical properties or toxicity (Duffus, 2002).

The term "heavy metal" usually refers to elements having densities greater than 5.0 (Adriano, 1986) in their elemental form comprise of 38 elements. Market (1993) reported that heavy metals are those metals which show a specific gravity >4.5 g/cm^3. Greenland and Hayes (1981) stated that heavy metals refer to twelve metals that are used and discharged by industry, i e., Cd, Cr, Co, Cu, Fe, Hg, Mn, Mo, Ni, Pb and Zn represent potential hazards to plants or animals. According to Philp (1995), metals with specific gravity less than 8 are mostly essential trace nutritional elements, whereas those having specific gravity greater than 8 are the more toxic ones. Some sources of heavy metals and other hazardous substances are presented in Table- 2.4.

Table- 2.4: Some Major Sources of Heavy Metals and Other Hazardous Substances in Environment

Major source/ Industry	Substance										
	As	Cd	Se	Cr	Cu	Cy	Pb	Hg	Zn	CH	Misc[++] organics
Battery		*					*	*	*		
Chemical manufacturing				*	*			*		*	*
Electrical and electronics			*			*	*	*		*	
Electroplating & metal finishing		*		*	*	*			*		
Explosives	*				*		*	*			*
Leather				*							*
Mining	*	*	*	*	*	*	*	*	*		
Paint and dye		*	*	*	*	*	*	*			*
Pesticides	*				*		*	*	*	*	*
Petroleum and coal	*						*			*	
Pharmaceuticals	*							*			*
Printing and duplicating	*		*	*	*		*				*
Pulp and paper								*			*
Rubber and plastic					*		*	*	*	*	*
Textile				*	*						*

(Source: Schmidtke, 1980); CH- Chlorinated hydrocarbons, + including PCB's, ++ i. e., acrolein, chloropicrin, dimethyl sulphate, dinitrobenzene, dinitrophenol, nitroaniline, pentachlorophenol

Mason (1991) revealed that the term heavy metal is somewhat imprecise, but includes most metals with an atomic number greater than 20, but excludes alkali metals, alkaline earth metals, lanthanides and actinides. Excessive levels of certain elements can be damaging to the organisms and that are normally toxic, that have no vital or beneficial effect on organisms, and their accumulation over time in the bodies of animals can cause serious illness or under certain conditions, beneficial.

2.2.1 *Toxicity of Heavy Metals*

Toxicity is the degree to which a substance can damage an organism. Toxicity can refer to the effect on whole organism, such as an animal, bacterium, or plant, as well as the effect on a substructure of the organisms, such as cell (cytotoxicity) or an organ such a liver (hepato-toxicity) (Web. 2). Toxins are heavy metals and chemicals that are harmful to our body.

Toxic substances are commonly referred to xenobiotics. These foreign substances are poisonous to our systems; they do not allow cells to work properly and we get sick. Toxicology is dose-dependent, even water can lead to water intoxication when taken in too high a dose. And there is no beneficial dose for a toxic metal with a biological role. There are generally three types of toxic entities: physical, chemical and biological. Chemical toxicants include inorganic substances such as Pb, Hg, Cd, Cu, Zn, Ni, Cr, As, hydrofluoric acid and chlorine gas, and organic compounds such as methyl alcohol, most medications and poisons from living things. Biological toxicants include bacteria and virus that can induce disease in living organisms. Biological toxicity can be difficult to measure because the 'threshold dose' may be a single organism. Physical toxicants are substances that, due to their physical nature, interfere with biological processes.

All soils contain heavy metals. In non heavy metal soils, the concentrations of Zn, Cu, Pb, Ni, Cd and Cr range between 0.0001 and 0.065%, whereas Mn and Fe can reach 0.002% and 10%, respectively (Ernest, 1968). With the exception of iron, all heavy metals above a concentration of 0.1% in the soil become toxic to plants and therefore change the community structure of plants in a polluted habitat. And, each plant species has a specific threshold value for each heavy metal, where it exerts toxicity (Ernest, 1996). Although many metal elements are essential for the growth of plants in low concentrations, their excessive amounts in soil above threshold values can result in toxicity. This detrimental effect varies with the nature of an element as well as plant species. The bioaccumulation of heavy metals in excessive concentrations may replace essential metals in pigments or enzymes disrupting their function and causing oxidative stress. Heavy metal toxicity hinders the growth process of the underground and aboveground plant parts and the activity of the photosynthetic apparatus (Shah *et al.*, 2010). And, the toxic concentration, normal concentration and permissible limits of heavy metals in soils and plants are presented in Table- 2.5, 2.6 and 2.7.

Table- 2.5: Toxic concentration levels of heavy metals in different plants

Element	In different plants (μg/g DM)	Barley (μg/g DM)	Normal concentration in plants (μg/g DM)
Cd	5-20	6-10	<0.1
Co	10-20	3-9	0.5
Cr	1-2	5-20	0.3
Cu	15-20	14-25	11.0
Hg	0.50-1	2-5	0.02
Ni	20-30	11-13	2.0
Pb	10-20	20-35	2.0
Tl	20-30	11-45	<0.1
Zn	150-200	120-220	60.0

(Source: Sauerbeck, 1982)

Table -2.6: Normal concentrations of different heavy metals in soils and crops

Element	Soil (mg/kg DM)	Plants (mg/kg DM)
Zinc	20-100	20-100
Chromium	10-50	0.10-0.50
Nickel	20-60	0.2-2.0
Copper	10-50	3-12
Lead	10-30	0.10-0.50
Cobalt	2-10	0.02-0.50
Cadmium	0.05-1	0.05-0.50
Mercury	0.05-5.0	<0.01-0.05
Arsenic	1-10	0.1-0.50

(Source: Horak, 1996)

Table- 2.7: Permissible limits of heavy metals in soils, sewage sludge and city wastes

Element	Soil (mg/kg)	Sewage sludge (mg/kg)	City wastes (mg/kg)
Zn	300/150*	1600	1000
Cu	100	400	400
Ni	60	80	100
Cr	100	400	150
Pb	100	400	500
Cd	1	5	4
Hg	1	7	4

(Source: Horak, 1996)   For soil pH < 6.0

2.2.2 Heavy Metals in Environment

2.2.2.1 *Copper (Cu)*

The various sources of Cu in the environment are industrial copper use (i.e., in making containers such as boilers, stream pipes, automatic radiators and utensils), copper pesticides, bacteriocides, fungicides, algicides in water purification and in the form of fertilizers, vehicle fluids leaks and dumping, vehicle brake pads and architectural and marine antifouling coating of copper etc. Out of these, industrial effluents are the largest.

Krauskopf (1979) stated that Cu ranked 26th among the elements in crustal abundance and Cox (1979) revealed the average crustal abundance of Cu range from 24 to 55 ppm. Bowen (1979) cited it 50 ppm. Gilbert (1952) reported the average value for total Cu content of world soils is 30 ppm, which ranging from 2 to 250 ppm. For normal agricultural soils, total Cu is expected to range from 1 to about 50 ppm. Depending on the extractant used, the available Cu in agriculture soils may range from only 0.1 to 10ppm (Baker, 1974).

As Cu is strongly fixed by organic matter, oxides of Fe, Al and Mn, and clay minerals, applied or deposited Cu will persist in soil (Gilbert, 1952; Schnitzer, 1969; Baker, 1974). It is one of the least mobile of the trace elements, thereby rendering it uniformly distributed in many soil profiles. In agricultural soils, Cu may be expected to accumulate in the surface from fungicide applications, soil amendments, and by accumulation from crop residues (Wright *et al.*, 1955).

Copper is one of the seven micro-nutrients (Zn, Cu, Mn, Fe, B, Mo and Cl) essential for normal plant growth. Copper is required in very small amount and 5 to 20 ppm in plant tissue is adequate for normal growth (Jones, 1972), while less than 4 ppm is considered deficient and 20 ppm considered toxic. Copper has been established as a constituent of a number of plant enzymes. It occurs as part of the prosthetic groups of enzymes, as an activator of enzyme systems, and as a facultative activator in enzyme systems (Gupta, 1979).

Absorption rates of Cu by plant roots are among the lowest for the essential elements (Graham, 1981). The absorption process has been characterized as active, once absorbed Cu accumulates in roots, even in cases where roots have been damaged by toxicity (Jarvis, 1978). Kubota (1983) found a median concentration of 8.4 ppm Cu in the dry matter for US legumes (range of 1 – 28 ppm); the median value for grasses was much lower 4 ppm (range of 1-16 ppm). Davis *et al.* (1978) found that 20ppm Cu in the shoots of sparingly barley grown in sand culture (4 ppm Cu in solution) was critical for its growth. Chino (1981) reported that for rice, toxic levels in tops were in the range of 20 to 30 ppm Cu; in roots, toxic range was from 100 to 300 ppm. Agarwala *et al.* (1977) ranked the following heavy metals is inducing visual toxicity symptoms in barley as follows: $Ni^{2+} > Co^{2+} > Cu^{2+} > Mn^{2+} > Zn^{2+}$. In rice, Chino and Kitagishi (1966) found that the toxicity of metals follow the order: Cu> Ni> Co> Zn> Mn, which correspondingly follows the order of the metal electro-negativity. Hewitt

(1953) observed that Cu consistently induced Fe chlorosis in crops that were susceptible to Cu toxicity.

Phyto-toxicity of Cu could be predicted by Cu concentrations in soils, either on total or extractable basis. Generally, Cu toxicities have been associated with soil Cu levels of 150 to 400 ppm (Baker, 1974). On the other hand, Lexmond and de Haan (1980) suggested that, in soils with pH of 4.5 to 6.5, soil Cu may become phyto-toxic when 20 to 30 ppm of HNO_3-extractable Cu is present for each l% of soil organic carbon. Delas (1980) noted that the threshold values of soil-Cu phyto-toxicity were about 25 ppm of NH_4^+ extractable Cu for sandy soils and 100 ppm in clay soils. Similarly, Drouineau and Mazoyer (1962) reported the limit as 50 ppm NH_4^+ exchangeable Cu in soils with pH 5.0 and 100 ppm in soils with pH 6.0 to 7.0. The most common Cu toxicity symptoms include reduced growth of vigor, poorly developed and discolored of root systems, and leaf chlorosis (Robson and Reuter, 1981). In addition, Cu toxicities causes stunting, reduced branching, thickening, and unusually dark coloration in the rootlets of many plants (Reuther and Labanauskas, 1965). And, the chlorotic symptoms in shoots often resemble those of Fe deficiency.

2.2.2.2 *Zinc (Zn)*

Zinc is a metallic element that has many industrial applications. Zinc is unaffected by dry air and in moist air; it is oxidized and becomes coated with a carbonate film that protects it from further corrosion.

Zinc is the 24th most abundant element in the earth's crust, with the average value quoted as 70 ppm (Krauskopf, 1979). Domingo and Kyuma (1983) reported it 66 ppm for tropical Asia and 68 ppm for Bangladesh. Berrow and Reaves (1984) reported a mean content of total Zn of 40 ppm for world soil. The average dietary intake of Zn is about 16.1 mg (Kannan, 1997). The emetic dose of Zn as a salt is about 300 mg, large doses of zinc salt (220-440 mg as $ZnSO_4$) cause gastrointestinal disorders including vomiting and diarrhea.

According to Cammarota (1980), zinc ranks fourth among metals of the world in annual consumption and most of the Zn produced in the world comes from ores containing Zn sulphide minerals. The higher concentration lies in ZnO (80.3%) and ZnS (67%). It is used to manufacture dry cell batteries, parchment papers, glass, automobile tires, television screens, printing and dyeing of textiles, as a flux in metallurgical operations, wood-preservatives, agricultural micronutrient fertilizers, insecticides, construction materials etc. It is also used for protective coatings on iron, steel, brass and alloys. Municipal refuse and automobile (tire wear, fuel additives, brake linings and motor oils) serve as additional sources.

Zinc is fairly uniformly distributed and in soils is easily adsorbed by mineral and organic substances, accumulating primarily in the soil surface layer. Zinc soil chemistry is quite complex in terms of its various combined ionic forms, with Zn being the most readily soluble of all the heavy metals in soils (Pais and Beaton, 1997). Zinc distribution in the soil profile

can be generalized that extractable Zn decreased with depth, while total Zn was somewhat uniformly distributed throughout the profile, although there were exceptions (Nakos, 1982).

The availability of Zn in soil is conditioned by adsorption, desorption, chelation and transport of ions from soil to root surface. It was reported that Zn in soil is mainly associated with hydrous Fe and Al oxides (14-38 percent of the total Zn) and with clay minerals (24 - 62 percent of the total Zn), whereas the readily mobile fractions and its organic complexes constituted about 1 - 20 percent and 1.5 - 2.3 percent, respectively. The adsorption of Zn in soil is highly influenced by the amount and type of clay, organic matter content, soil pH, calcium carbonate and oxides of iron and aluminium (Bulbul, 2003).

The dominant role attributed to Zn in plant system is its function in the synthesis of auxin. It acts as a component part of catalytic system and the absence of which affects the growth and yield of plants. Zn is easily distributed to various plant parts (Bodek *et al*., 1988; Taiz and Zeiger, 1991). On the other hand, Price *et al*. (1972) have cited several investigations to show that Zn deficiency causes sharp decrease in the levels of RNA and ribose contents. As reported by Jones (1972) the normal range of Zn concentration in mature leaf tissue ranges between 25 - 150 ppm. Deficiency occurs when the concentration is less than 20 ppm and toxicity is recorded when concentration exceeds 400 ppm (Bulbul, 2003). Kannan, (1997) reported that the mean total Zn content of tropical Asian paddy soils ranges from 35 to 88 ppm. And, Zn at 460 ppm in paddy soils causes a 10% reduction in yield and in fact, in the ranges between 250 - 1000 ppm, it may potentially be harmful to rice plants. The toxicity of Zn may be reduced at increased levels of Ca and Mg.

Occurrence of Zn toxicity has been associated with Zn smelting (Singh and Lag, 1976), naturally high localized Zn concentrations (Staker and Cummings, 1941), or production practices that add extremely large quantities of Zn to the soil (Lee and Page, 1967). Zinc concentrations in Southeastern United States soils that produced toxicity to corn ranged from 450 to 1400 ppm extractable Zn, and the cow peas, from 180 to 700 ppm (Gall and Barnette, 1940). Once the levels of Zn in plant leaf exceed 400 ppm, toxicities can be expected (Jones, 1972). In pot experiments, with different soil types and rates of Zn up to 250 ppm in soil, Zn concentrations of 792 ppm in corn, 523 ppm in lettuce, and 702 ppm in alfalfa, were associated with yield depression (MacLean, 1974). Some species such as pea are sensitive to even low Zn level in tissues; 50 ppm can introduce toxicity and reduced growth (Melton *et al*., 1970).

Chino (1981) reported that in Hokkaido, Japan 10% reduction in yield occurred when extractable (0.1 N HCl) Zn was 460 ppm in paddy soils. Ichikura *et al*. (1970) told that from 250 to 1000 ppm of total Zn in soil was harmful to rice plants. Chino (1981) summarized the Zn toxic levels for rice tops ranged from 100 to 300 ppm, and rice roots 500 to 1000 ppm.

Zinc is, thus an essential element in human and animal nutrition but its accumulation in amounts higher than normal in soils and plants cause harmful and also an environmental concern.

2.2.2.3 *Nickel (Ni)*

Nickel is the 24th most abundant metal in the earth's crust and 5th most abundant element by weight constituting about 3% of the earth composition (ATSDR, 2005). It is a silvery white metal, lustrous, malleable and ductile, resist corrosion, soluble in acids except concentrated HNO_3, unaffected by alkalis (Pais and Benton, 1997). Nickel was first isolated from the mineral niccolite by a Swedish Chemist Axel Crostedt in 1751.

Nickel has many industrial uses such as coinage manufacture, electroplating, ink and dyeing industry, paint making, refining and petroleum industries, smelting industry, stainless steel, cement manufacture, ceramics production, disinfectant industries, varnish, nickel alloy production, spark plug and other ignition devices, as well as, electrical resistance heaters and batteries (USPHS, 1977; Kotov and Nikitina, 1996; WHO, 1991; Kabata- Pendias and Mukherjee, 2007) food processing, as well as, in the manufacture of cables and wires, fasteners, motor vehicles, jet turbines, ship building, surgical implants and textiles (Kasprzak, 1987; USPHS, 1993; DEPA, 2005).

Nickel content in soils varied widely and has been estimated to range from 3 to 1000 ppm; for the world soils, the brand range is between 0.2 and 450 ppm, while the grand mean is calculated to be 22 ppm (Bencko, 1983; Kabata-Pendias and Pendias, 1992; Scott-Fordsman, 1997; Compel and Nikel, 2006). On the other hand, Duke (1980) reported that an average natural Ni content in the earth's crust was 86 ppm. Chen *et al*. (1999) also reported that in the rural soils of the world, Ni concentration differed among the countries such as Australia (60 ppm), Canada (150 ppm), China (20 ppm) and United State of America (420 ppm) etc. In fact, industrial waste materials, lime, fertilizer and sewage sludge constitute the major sources of nickel into soils (McIlveen and Negusanti, 1994). With decreasing pH, the solubility and mobility of nickel increases, hence, soil pH is the major factor controlling nickel solubility, mobility and sorption, while clay content, iron- manganese mineral and soil organic matter being of secondary importance (Anderson and Christensen, 1988; Ge *et al*., 2000; Suavé *et al*., 2000; Tye *et al*., 2004).

Generally, the distribution of Ni in soil profile is uniform, with typical accumulation at the surface soil due to deposition through anthropogenic activities (Compel and Nikel, 2006). Nickel can also exist in several forms in soils that include adsorbed or complex on organic cation exchange surfaces or on inorganic cation exchange surfaces, inorganic crystalline minerals or precipitates, water soluble, free-ion or chelated metal complexes in soil solution (Bennett, 1982; EHC, 1991). In the presence of fulvic and humic acids, the complexes are

much more mobile, and may be prominent than the hydrated divalent cations in soil solution (ATSDR, 2005).

Nickel toxicity levels vary widely between 25 to 50 ppm (Mishra and Kar, 1974). However, Gregson and Hope (1994) reported that the phytotoxic concentrations of Ni occurred at leaf contents of 10 to 100 ppm depending on the plant species, while, Kabata- Pendias and Pendias (2001) reported phytotoxic range of 40 to 246 ppm in the dry weight of plant tissue, depending on the plant species and cultivars. The most common plants that have been identified for their tolerance to and hyper accumulation of Ni include cabbage, cauliflower and turnip, as well as, leguminosae such as bean and pea (Kabata-Pendias and Mukherjee, 2007). Moreover, Uren (1992) found that besides inhibiting plant growth, other symptoms of Ni toxicity include chlorosis, stunted root growth and brown interveinal necrosis. The toxic effects of Ni result from its ability to replace other metal ions in enzymes, proteins or bind to cellular compounds (Compel and Nikel, 2006), and among animals, micro-organisms and plants. Prolong exposure to oxides and sulphides of Ni is associated with possible risk to lung and nasal tumors, while systematic effects whose initial symptoms are mild nausea, headache, dyspnoea, and chest pain, asthma, pneumoconiosis and irritation of nasal membranes (Klein and Snodgrass, 1977; El- Hinnawi and Hashmi, 1988; Kabata-Pendias and Pendias, 1992).

2.2.2.4 *Lead (Pb)*

Lead is one of the well-known environmental toxic metals and is a major pollutant with increasing concern of man. Pb pollution can affect all environments, but its effects are most long lasting in soils. It is the least mobile of all heavy metals in soils. It accumulates primarily on the surface, where its increasing presence may begin to affect soil micro-flora. Pb is not readily soluble in water and is found in relatively low concentration (Pais and Beaton, 1997). Total Pb content in soils ranged from 3 - 189 mg/kg (natural background level 10-67 mg/kg, mean 32 mg/kg; soluble content in soils: saturated paste, 5.0 mg/L). The maximum permissible limit in earth crust is <10 mg/L and soil 100 mg/kg soil. Lead affected soils contain Pb in the range of 400 - 800 mg kg^{-1} soil, whereas in industrialized areas the level may reach up to 1000 mg Pb/kg soil (Angelone and Bini, 1992).

In soils, this metal is largely immobile and a long half-life with very little leaching due to adsorption to soil clays, phosphates, sulfates, carbonates, hydroxides and organic matter. High concentration in soils may inhibit microbial processes and reduce decomposition processes. The Pb content of soil samples fell off rapidly with the increase in distance from highways. However, pathogenic processes, climate and topographic effects and microbial activities influence the distribution of Pb in the soil profile. And, Pb generally accumulates in the soil surface, usually within the top few centimeters and diminishes with depth (Ardiano, 1986 and Alloway and Ayers, 1993). Increasing acidity of soils from fertilizers and acid rain

further increased the solubility of this metal. Human activities can induce the reduction of concentration or its toxic effects in the environment (Beri and Setia, 1995).

Lead is a prime pollutant in both terrestrial and aquatic ecosystems. Besides natural weathering processes, the main sources of Pb pollution are exhaust fumes of automobiles, chimneys of factories using Pb, effluents from the storage battery, industry, mining and smelting of Pb ores, metal plating and finishing operations, fertilizers, pesticides and additives in pigments and gasoline and textile (Eick *et al*., 1999). Most of the Pb once produced remains in soil, dust and other environments. The fate of anthropogenic Pb in soils has recently received much attention, because this metal is hazardous to human and animals from two sources such as the food chain and soil dust inhalation. In urban areas, automobile exhaust contributes substantially to the atmospheric pollution. Plants growing near highways are usually exposed to more Pb than the localities. Sewages sludge containing large quantities of Pb and other metals is regularly discharged on to field and garden soils due to increasing trends in urbanization (Paivoke, 2002).

According to the DOE (1997), due to the increased use of fossil fuel, coal and an increased production of waste by the industries, automobiles exhaust accounts for about 50% of the total inorganic Pb absorbed by human. In Bangladesh, leaded gasoline used in automobiles enhanced the concentration of Pb in road side soils. Venkatesh and Abhimanya (1998) found 45 - 455 ppm Pb in road side soils, which was much higher than the background level (0 - 24 ppm). According to Lenore *et al*. (1998), Pb is removed from the atmosphere by wet and dry deposition processes. As a result of these processes, street dusts and roadside soils become enriched with 1000 - 4000 mg kg^{-1} Pb on busy streets.

Since microorganisms and plants show strong tendency to bio-accumulate Pb, there is a possibility that the bio-accumulated Pb may enter into the terrestrial food chains (Deuny, 1987). Nriagu (1988) considered that Pb poisoning must be regarded as the most prevalent public health problem in many parts of the world.

2.2.2.4.1 *Pb in Soils and Plants*

Bodek *et al*. (1988) reported that Pb uptake was passive and the translocation from roots to other plant parts was low but aerial deposition and foliar uptake contribute significantly to leafy concentrations and that anaerobic conditions (e.g., flooding). Low pH and low phosphate concentration promote Pb uptake. Santo-Diaz *et al*. (1992) noticed that all Pb compounds greatly increased Pb uptake and plant tissue concentrations of rice plant.

 Lead is available to plants from soil and aerosol sources. Pb uptake studies in plants have demonstrated that the roots have an ability to take up significant quantities of Pb, whilst simultaneously greatly restricting its translocation to above ground parts (Lane and Martin, 1977). Miller and Koeppe (1971) demonstrated that *Zea mays* plants could translocate and accumulate significant quantities of Pb in the leaves. The extent to which Pb enters into

plants via the leaves depends on the ability of leaves to absorb Pb from aerial sources, which in turn depends on the specific root morphology.

Hughes *et at*. (1980) extensively reviewed the findings on Pb absorption by roots and concluded that the mode of its uptake is passive and that the rate of uptake is reduced by liming and by low temperature. Likewise, Pb although not readily soluble in soil, is absorbed mainly by root hairs and is stored to considerable degree in cell walls.

Zimdahl (1975) described that when Pb is present in soluble forms in nutrient solutions, plant roots are able to take up great amounts of this metal, the rate increasing with increasing concentration in the solutions and with time. The translocation of Pb from roots to tops is greatly limited. Only 3% of the Pb in the root is translocated to the shoot.

Zimdahl and Koeppe (1977) showed that under certain conditions Pb is mobile within the plant. It is generally agreed, however, that Pb from a soil source is not readily translocated to edible portion of plants. These authors stated that the main process responsible for Pb accumulation in root tissue is the deposition of Pb, especially as Pb pyrophosphate, along the cell walls.

Malone *et al*. (1974) identified the deposit of Pb in cell walls outside the plasmalema as Pb crystals. Similar deposition of Pb was observed in roots, stems and leaves suggest that Pb is transported and deposited in a similar manner in all tissues of the plant.

Kumar *et al*. (1995) stated that the bulk of the Pb was taken up by plant remains in the roots. Broyer *et al*. (1972) also agreed with the statement that large portion of Pb taken up from solution culture is associated with roots. Jones *et al*. (1973) confirmed that plant roots restrict Pb movement into shoots. On the other hand, Baumhardt and Welch (1972) conducted a field experiment by using Pb-acetate at rates ranging from 0 to 3200 kg/ha, Pb concentration in corn foliage was significantly increased by Pb application and the Pb content in corn grain was not affected by added Pb. Their results indicate that Pb was absorbed by the roots and translocated to the plants tops, but it was not translocated from the stover to the grain.

Morel *et al*. (1986) reported that at the root surface Pb binds to carboxyl groups of mucilage uronic acids. Mucilage binding restricts metal uptake into the root and establishes an important barrier protecting the root system. Some of the bound metals are released when mucilage is biodegraded.

Some micro-organisms may affect heavy metal availability by the process of bio-sorption, bioaccumulation and solubilization. It was shown by Marschner and co-workers (1996) that ectomycorrhiza could influence uptake, transport and toxicity of Pb in *Norway spruce* plants.

Rolfe (1973) showed that Pb uptake by eight tree species grown on soils treated with five soil Pb levels (0 to 600 ppm) was significantly affected by soil Pb concentration with higher accumulation in roots, lower levels in the stems and leaves and the uptake studies of forage

crops indicated that only a very small fraction (0.3% to 0.5%) of added Pb was utilized by the plants.

2.2.2.4.2 Phytotoxicity of Pb

According to Kannan (1997), extremely low levels (2 to 6 µg/kg) of Pb may be necessary for plant, as there is some evidence of a stimulatory effect at low concentrations.

Lee *et al.* (1976) found increased respiration rate, increased activities of the enzymes, acid phosphates, peroxidase and alpha-amylase, and increased levels of soluble protein and ammonia with Pb treatment. Conversely, Khan and Frankland (1983) found that in radish plants grown on soil, Pb toxicity was manifested as stunted growth, which is more pronounced in roots than in shoots. According to Adriano (1986), Pb interfere ion uptake and translocation, growth retardation due to inhibition of mitochondrial respiration, and inhibition of chloroplast activity. Similarly, Patrick and Bisessar (1991) reported that dry matter production of onion, potatoes, cabbage, and lettuce was inhibited by Pb and Ni toxicity.

Liu *et al.* (2003a) reported that Pb at low concentration could promote normal physiological and metabolic activities in plants such as the activities of nitrate reductase, the contents of soluble sugar and chlorophyll of stems and leaves, whereas at higher concentration severely affected normal physiological and metabolic activities in plants, resulting in the symptoms of leaf etiolating and withering of stems and leaves. It was also reported that Pb treatment affected mitochondrial respiration in corn (Koeppe and Miller, 1970); altered photosynthesis in soybean (Bazzaz *et al.*, 1974; Huang *et al.*, 1974); and inhibited photosynthesis electron transport in isolated spinach chloroplast (Miles *et al.*, 1972). Mesmer *et al.* (1991) reported that excess Pb in *Triticum sativum* and *Lens esculenta* alters several physiological and biochemical processes in both species. They further reported that Pb inhibited the growth of both shoots and roots, but root growth inhibition was more pronounced than the shoot. Tivot *et al.* (1985) and Chen *et al.* (1991) reported that seed germination, shoot and root growth and seedlings chlorophyll content of brown rice and wheat were decreased by added Pb. All Pb compounds greatly enhanced Pb uptake and plant tissue concentrations. Wagatsuma *et al.* (1985) found that excess Pb inhibited the growth of rice and aduki bean. Baumhardt and Welch (1972) and Rolfe (1973) reported that Pb was toxic to plants except in very low concentration, and when Pb was absorbed by plants leading to reduction of growth and inhibition of cell division. Likewise, Zimdahl (1975) reported that even a very low Pb concentration may inhibit some vital plant processes.

Lubis (1988) reported that Pb toxicity decreased weight of grains of rice plants. *Sesbania sequester* absorbed high content of Pb, Cu and Zn and consequently the seedlings turned yellow and in some cases died. It was also reported by Shahi *et al.* (1999). According to Chatterjee *et al.* (2006), excess Pb reduced the dry weight and grain yield. Pb accumulation reduced the concentrations of chlorophyll in leaves, carotene, sugars, phenols, non-protein nitrogen, protein, iron, manganese, copper, zinc, and peroxidase activity, but increased the

concentrations of sulphur, phosphorus, magnesium (early stage), protein nitrogen, and activity of catalase, acid phosphorus, and ribonuclease in leaves of rice. Except for slight growth depression and reduction in number and size of leaves, tillers and inflorescence, no other visible symptoms of excessive Pb could be seen before harvesting.

In rice, the decreasing order of phyto-toxicity (Chino, 1981) of different metals is: Cd >Cu >Co = Ni >AS = Cr > Zn > Mn = Fe > Pb. Davis *et al*. (1978) found that 25 mg/L of Pb in solution used in sand culture was the critical level for barley growth. For oat and tomato plants, Berry (1924) found that a concentration of Pb as Pb $(NO_3)_2$ of 25 mg/L was required to cause toxicity and at a concentration of 50 mg/L, plant death occurred. According to Kannan (1997), Pb at 30 mg/L in nutrient solution has been found to be toxic to plants, with 10 mg/L slowing plants growth and 100 mg/L being lethal. In some types of plants, Pb can be as high as 350 mg/kg in plant tissue without visible harm. In rice plants, Chino (1981) found the following toxic levels for Pb: 50 to 2000 ppm in tops and 300 to 3000 ppm in roots. Total Pb amounting to 400 to 500 ppm in the soil in a polluted area in Japan was found to be toxic to the plants. Huang *et al*. (1974) indicated that Pb at a concentration of 300 µM inhibited pod fresh weight in soybeans. Strand *et al*. (1990) came with the findings that Pb at concentration of 100 mg/kg soil reduced grain yield of barley, potato tuber and maize by 47.5, 30, 40.3 and 71% respectively.

Lead can be readily absorbed by plant roots, but little (less than 3%) is translocated to the tops. Leafy vegetables such as lettuce, spinach, potatoes and beans are likely to absorb more Pb, whereas fruiting crops such as tomatoes, corn, beats, squash, eggplant and peppers do not pick up any appreciable amount of Pb through their root systems. According to Karathanasis (1999), the presence of suspended ex-situ colloidal particles in flushing solution may enhance Pb desorption and remobilization in contaminated soils.

2.2.2.5 *Cadmium (Cd)*

Cadmium is considered as one of the most toxic heavy metals in the environment and has no function in the plants and animals. This metal is ranked number seven among the top toxins, mainly due to negative influence on the cell's enzymatic system (ATSDR, 1999), and it has been estimated that 70% of the Cd intake by humans comes from plant foods (Wagner, 1993). Among heavy metals, Cd is readily taken up by plants and translocated to different plant parts (Florijn and Van Beusichem, 1993; Li *et al*., 1995 and Sarwar *et al*., 2010). According to Adriano (1986), Cd is twenty times more toxic than Pb. Of all the metals, Cd is one of the most important to consider in terms of food-chain contamination. Under normal condition, plants take up small quantities of Cd from soil. Huffman and Hodgson (1973) found that the levels of Cd were generally below 0.30 ppm (wheat = 0.20 ppm, n = 33; grasses = 0.17 ppm, n=120) and there were no distinct regional pattern of Cd concentration. Total Cd content in soils ranged from 0.01 - 3.0 mg/kg and soluble content in soils ranged 0.1 - 14.0 mg/kg. Content in plant ranged from 0.1 - 1.0 mg/kg; reference plant, 0.05 mg/kg and

3 mg/kg will reduce plant growth. Cd contaminations impose an adverse effect on environmental quality and constitute a serious threat not only to plants and animals but also to human lives (Martin-Garin *et al.*, 2002). The regulation levels of soil Cd, total contents range from 1 to 5 mg kg^{-1} throughout the world. The upper limit for background Cd contents of representative rural soil is 3 mg/kg, most of the corresponding brown and polished rice is considered to be Cd-contaminated rice (Chen, 1991). Cadmium is extremely toxic and accumulates in the kidneys and liver, with prolonged intake at low levels sometimes leading to dysfunction of the kidneys.

Cadmium is produced commercially as a byproduct of the Zn industry. The most important uses of Cd are as alloys in electroplating (auto industry), in pigments, cement, plastic, fertilizer, metal alloys, as stabilizers for polyvinyl plastics, and in batteries (Ni-Cd batteries). It is also used in photography, lithography, process engraving, rubber curing and as fungicides, primarily for golf course greens, pigments used in ceramics, paints in textiles and coatings, electronics and autos (Adriano, 1986 and Sanita di Toppi and Gabrielli, 1999). Increasing concentrations of Cd have been observed in agricultural soils due to long term application of phosphorus fertilizers and sewage sludge (Joarder, 2003 and Stephens and Calder, 2005). With the development of modern industry and agriculture, Cd has become one of the most harmful and widespread pollutants in agricultural soils, and soil-plant-environment system mainly due to industrial emission, application of Cd containing sewage sludge and phosphate fertilizers and municipal waste disposal (Gupta and Gupta 1998; Wu *et al.*, 2003, 2004, 2005; Lima *et al.*, 2006).

2.2.2.5.1 *Cadmium in Soils*

Cadmium is fairly immobile in the soil profile. The Cd level (≤ 1 ppm) is fairly uniform throughout the profile, and apparent mobilization also occurred in very poorly drained profiles (Adriano, 1986). Soils contaminated by smelting operations showed Cd concentrations close to background level at a depth of about 30 to 40 cm. Anderson and Nilsson (1972) indicated that practically all of Cd remained in the surface 20 cm of soil following application of 84 tones/ha of sewage sludge over a 12-year period. Cd retention in soils is influenced by soil properties such as CEC of soil, pH, organic matter content (Adriano, 1986), and Fe_2O_3 content. Similarly, Kuo and McNeal (1984) found that sorption of Cd by hydrous iron oxides conformed to the Langmuir isotherm. Street *et al.* (1977) reported that Cd solubility in soils decreased as pH increased. The lowest values were obtained in the calcareous soils (clay loam at pH 8.4). Anderson (1977) observed the effects of clay particles on the mobility of Cd in soils. He stated that the mobility of Cd mostly in soil is reduced by the clay particle of the soil. In addition, Cd was relatively mobile in acid soil and its mobility increases with increasing the acidity of the soil. It was observed that the mobility of Cd was reduced in acid soil by interaction with the oxides/hydroxides of Fe and Al (Bulbul, 2003).

2.2.2.5.2 *Phytotoxicity of Cd*

Cadmium is an important toxicant in affecting plant productivity (Prasad, 1995; Thiebeauld *et al.*, 2005; Wahid *et al.,* 2008) and has a long biological half-life (Himly *et al.*, 1985).

 The levels of Cd in the tops of ten plant species grown without added Cd in a neutral soil ranged from 0.21 ppm in timothy to 0.71 ppm in soybean leaves (MacLean, 1976). In Japan, 1 to 50 ppm Cd concentration in rice fields was reported and much Cd contents in plant tissues had been reported (Yamagata and Shigematsu, 1970). The critical Cd level in nutrient solution for conventional crop plants is reported to be 8 mmol/L (Yang *et al.*, 1995). Nevertheless, cereals such as maize, rice, and barley can tolerate Cd as much as 100 mmol/L (Inouhe *et al.*, 1994).

In Cd-enriched soils, plants may accumulate 20 mg/kg Cd in the shoots. In the case of maize, 23 mg Cd kg^{-1} in the shoot dry weight is considered the limit of phytotoxicity relevant for production (Klein *et al.*, 1981). Sarkunan *et al.* (1991) found that the grain and straw yields decreased with increase in Cd application above 10 ppm. The uptake of Cd can vary greatly among plant species and also among cultivars within a species (Penner *et al.*, 1995; Athur *et al.*, 2000; Zhang *et al.*, 2002).

Cadmium is phyto-toxic interfering different morphological and physiological disturbance such as photosynthetic and respiratory activities, mineral nutrition, enzymatic activities, membrane functions, and hormonal balance (Clysters and Van Assche, 1985; Boussama *et al.*, 1999; Chien and Kao, 2000; Benavides *et al.*, 2005). Likewise, Wahid *et al.* (2010) observed that the effects of Cd toxicity on above-ground parts include plant stunting, leaf rolling, chlorosis and necrosis, diminished stomatal conductance and gas exchange, perturbed leaf water and nutrient status, hormonal imbalance, production of oxidative stress, and enhanced peroxidation of membrane lipids. In addition, Allan and Jarrel (1989) and Wang *et al.* (2001) found that the activities of respiratory enzymes were inhibited and respiration rate decreased with the increasing concentration of Cd in plants. On the other hand, Gratao *et al.* (2005) observed that Cd induced the production of reactive oxygen species affecting important macromolecules and modifying the activity of enzymes related to the antioxidant defense system. Then again, Hernandez *et al.* (1996) reported that Cd reduced the absorption of nitrate and its transport from the roots to shoots, but inhibited the nitrate reductase activity in the shoots. Appreciable inhibition of the nitrate reductase activity was found in plants of *Silene cucubalus* (Mathys, 1975).

The following Cd concentration in edible tissue of greenhouse soil-grown plants were associated with 50% yield decrement (Bingham and Page, 1975): field bean, paddy rice, upland rice, sweet corn- ≤3 ppm; zucchini squash, wheat tomato, cabbage, beet, soybean- 10-20 ppm; turnip, radish, carrot- 20 - 30 ppm; romaine lettuce, Swiss chard, curlycress, spinach- > 80 ppm. These levels, although much greater than what can be expected of field-grown crops, are well above the normal levels of Cd found in the foodstuff, which is around

0.05 ppm (Frieberg *et al*., 1971). In young spring barley, the critical levels of Cd in plant tissues that affected their growth were about 15 ppm (Davis *et al*., 1978). Cd toxicity symptoms in crops, in general, resemble Fe chlorosis (Haghiri, 1973; Mahler *et al*., 1978). Cadmium toxicity reduce photosynthetic rate, internal water deficit in the vascular system caused by reduced conductivity of the stems and poor root system development, ion interactions in plants and possible inhibition of nutrient (N and P) mineralization in soil (Belimov *et al*., 2003; Huang *et al*., 2004).

Cadmium is taken up through the roots and accumulated mainly in the organ, but it can be also translocated to shoots, grains or fruits (Page *et al*., 1981). Maize roots have a great ability to retain Cd (Nocito *et al*., 2002), a feature that is largely desirable in the context of the food chain, thereby avoiding translocation of high quantities of Cd in the aerial part.

Wang *et al*. (2009) carried out a pot experiment for the selection of pollution-safe cultivar (PSC) of water spinach (*Ipomoea aquatic* Forsk.) and found that the high-Cd accumulating ability of water spinach was a stable biological property at cultivar level and, thus, was genotype dependent.

Hossain *et al*. (2007) studied on the transfer of Cd from soil to the vegetable crops and found that the transfer factor of Cd in roots of vegetables decreased in the order: Lettuce> Spinach> Data Sak> Lal Sak; while in shoots, it was Data sak> spinach> lettuce> lal sak and the transfer factor varied from 2.030 to 6.785 in roots and 0.166 to 0.525 in shoot.

Under Cd stress, tolerant species and genotypes in plant kingdom could reduce Cd activity to alleviate or eliminate its toxicity through regulating the physiological and biochemical metabolism. In order to survive, plants have to develop efficient and specific heavy metal detoxification mechanisms in different plant species (Punz and Sieghardt, 1993).

According to Dong *et al*. (2007), one of the main Cd tolerance mechanisms is involved in depressing Cd bio-availability in soils, thus reducing the amount of Cd uptake. Roots excrete some organic substances to rhizosphere during the growth, and rhizosphere controls the entrance of nutrients, water and other chemicals, beneficial or harmful to plants. In rhizosphere, a series of physical and chemical reactions of heavy metals take place that affect their transfer in soil- plant systems, which may be beneficial to decrease the metal availability and its absorption by plants.

Bingham *et al*. (1980) reported that the effect of Cd on the yield of rice varied significantly with soil pH. He also found that there were remarkable differences among rice cultivars for their sensitivity to Cd in dry matter accumulation and grain yield formation. Some cultivars were strongly tolerant to soil Cd stress, while others were very sensitive. So, the effects of Cd on rice growth and development appear to be variety dependent.

According to Quynh *et al*. (1997), the increase in the concentrations of Cd in soils caused higher levels of Cd in rice. The ratio of Cd in soil: Cd in roots: Cd in stems and leaves : Cd in husked rice was approximately 10 : 200 : 10 : 1. The influence depends on the rice variety.

According to Tachibana (2009), Cd tolerance and accumulation depends on the N accumulation efficiency of rice genotype. The higher the N uptake capacity of rice plants, the higher the Cd tolerance capacity and the lower the Cd uptake tendency. There is a consistency between N uptake capacity and Cd tolerance in rice plants. He also concluded that genotypic differences in Cd accumulation and toxicity could be, at least, in part, attribute to N uptake capacity in rice plants.

2.2.2.6 *Effect of Pb and Cd on the Accumulation of Monovalent and Divalent Cations by Plants*

Strand *et al*. (1990) found that the Pb treatments reduced the contents of N in rice straw and grains. An antagonistic effect on nitrogen uptake by rice plants due to applied Pb was also reported by Lee and Kim (1991). Several researchers (Trivedi and Erdei, 1992; Khan and Khan, 1983a and Kim *et al*., 1986) reported that the increasing Pb concentrations had an adverse impact on potassium (K^+) uptake by rice plant and reduced the uptake of K^+ significantly in straw and grain. Likewise, increasing concentrations of Pb significantly reduced the accumulation of Na^+ in grain and straw of rice plant as reported by Eriksson (1998) and Adamee (1989). Breckie and Kahle (1992) reported that Pb toxicity had an adverse effect on Na^+ uptake in beech trees.

Kim *et al*. (1986) revealed that the increasing Pb concentration in soil reduced Ca^{2+} contents significantly in rice plants. Lee and Kim (1991) found that Pb toxicity showed an antagonistic effect on Ca^{2+} and Mg^{2+} uptake in rice plants. Similarly, Ludger and Jager (1985) observed that with increasing Pb concentration in soil, reduction of Cu content in rice plants occurred. Breckie *and* Kahle (1992) observed an antagonistic effect on Cu uptake by beech trees due to Pb toxicity. Muchrimsyah and Mercado (1990) indicated that Pb treatment in soil decrease the uptake of phosphorus in rice and other plants. The decrease in uptake of Mn by rice plant at all levels of Pb was reported by Chen *et al*. (1991) and Wagastuma *et al*. (1985). Hirayama and Kobyashi (1989) reported that Mg uptake in rice plants decreased due to Pb toxicity.

Kim *et al*. (2002) found that the transport and toxicity of Pb^{2+} and Cd^{2+} were being affected by the presence of K^+, Ca^{2+} or Mg^{2+}, although K^+ had a little effect on uptake or toxicity of Pb^{2+} and Cd^{2+}. And, Ca^{2+} or Mg^{2+} blocked both Cd^{2+} transport into rice roots and toxicity on root growth, which suggested that their detoxification effect was directly related to their blocking of entry of the heavy metals. Grunhage and Jager (1985) found that Pb significantly reduced the Ca, Mg and Fe in plants.

In general, Cd has been shown to interfere with the uptake, transport and use of several elements (Ca, Mg, P and K) and water by plants (Das *et al*., 1997). Akay and Koleli (2007)

reported that P concentrations in grains decreased with increasing levels of Cd application. And, Vijayarengan (2012) found that with increasing Cd level in soil, decreased N, P, K, Na, Ca and Mg in rice plants.

2.2.2.7 *Pb and Cd Accumulation in Vegetables and Grasses*

Plants grown in Pb enriched soil are known to accumulate high levels of Pb (RCEP, 1983). Elevated Pb contents of vegetables grown in urban and industrial areas provide a health risk to human. Although some of the grass species are Pb tolerant, some have been found to contain high levels of Pb in the soil (RCEP, 1983).

Studies showed that with increasing concentration of Pb in the soil, the uptake by the vegetable plants increased. The highest bioaccumulation of Pb generally is reported for leafy vegetables (mainly lettuce) grown in surroundings of nonferrous metal smelters, where plants are exposed to Pb both from soil and air. In this location, highly contaminated lettuce may contain as much as 0.15% Pb (DW). Although market garden crops may be affected to some extent, the contamination of vegetables grown in urban gardens or municipal allotments is of much greater concern (Davies *et al.*, 1979).

Hibben *et al.* (1984) reported that radish and lettuce accumulate more Pb than other vegetables. Lettuce absorbed and accumulated the highest amount of heavy metals in roots and shoots followed by wheat. The transfer co-efficients for Cr, Zn, Cu, Hg, Mn, Cd, Ni and Pb in wheat and lettuce were investigated. In general, lettuce had the highest transfer coefficient. Similarly, Kannan (1997) and Dara (1998) suggested that leafy vegetables, potatoes and beans are likely to absorb more Pb than fruiting crops like tomatoes and beets. He also suggested that it was better not to grow carrots, turnips, beet and sprouts near highways where contamination by vehicular exhausts is more. Tyksinski *et al.* (1993) analyzed Pb, Cd, Cu and Fe in vegetables grown in city Poznam and found that 53.7% of leafy vegetables, 26.9% rooty vegetables and 40% of vegetable crops and their fruit contained excessive concentration of Pb. On the other hand, Ullah *et al.* (1999) observed that soils of Tejgaon contaminated with heavy metals severely affected lettuce growth and in some cases caused death. Indian spinach is a widely accepted vegetable in this country and this leafy type of vegetables has a tendency to take up large amount of Pb grown on by roads and industrial sides (Davies *et al.*, 1979; Hibben *et al.*, 1984; Ullah *et al.*, 1999). In contrast, Rotkittikhun *et al.* (2007) working on metal tolerance and metal uptake by two grasses and found that both T.*maxima* and V. *zizanioides* could tolerate high Pb concentration in soil (10 - 750 mg/kg) and had showed very good growth performance.

2.2.3 *Heavy Metals Pollution in Bangladesh*

Pollution is defined as an undesirable change in the physical, chemical or biological characteristics of our air, land and water that may or will harmfully affect human life or that

of over desirable species, our industrial processes, living condition and cultural assets or that may or will waste or deteriorate our raw material resources (Kudesia, 2003).

Ullah *et al*. (1995) reported that huge amounts big and small polluting industries in and around Dhaka city were discharging heavy metals like Fe, Mn, Zn, Cu, Cr, Ni, Cd and Pb along some sodium phosphate, nitrates and nitrites and were deteriorating the natural water quality of Dhaka city day by day. On the other hand, after investigating soil, effluent and plant samples collected from areas adjacent to pharmaceuticals and battery industries (Tongi) and tannery factories (Hazaribagh), Nuruzzaman *et al*. (1993) found three times (February, May and December of 1992) higher heavy metals concentrations at those locations and excessive concentrations of several heavy metals were also observed even up to 4 km away from the industries.

According to Shabnam *et al*. (2008), the rivers around the industrial belts of Dhaka, Narayanganj, Chittagong and Khulna are major receiver of untreated effluents coming from tanneries, textiles, chemicals, pesticides, medicines, foods, engineering etc. According to Miah *et al*. (2010), industries around Dhaka city do not have proper waste management systems. They carried out a study around Dhaka city to observe the contribution of various industrial wastes to environmental degradation particularly to soil and plant. Effluents from discharge points, soils where the effluents were released and plant samples were collected from twelve industrial sites of four different areas(viz. Savar, Tongi, Tejgaon and Shampur) and were analyzed for different environmental hazardous parameters like pH, EC, TDS, TSS, BOD, Pb, Cd, Zn and Cu. In the effluent, they found that the values were higher than the safe limit except Cd, Zn and Cu. The heavy metal content in soil and plant was within the typical range except a few cases.

Imamul Haq (1998) reported that the tannery industries are one of the most important and largest businesses in Bangladesh, except very few, most of them do not have any effluent treatment plant and discharge huge amount of untreated wastes and effluents. These waste materials were rich in Na, various organic substances and numerous heavy metals such as Cr, Cd, Pb, Cu, Zn and Mn etc. On the other hand, Shabnam *et al*. (2009) collected untreated wastes and effluents from Hazaribagh tannery area and found comparatively higher amounts of N, S, P, Na, K and the heavy metals such as Cd, Cu, Pb and Zn compared to the Nayarhat tannery area, where effluent treatment plants was in operation.

The uptake of heavy metals by plants from contaminated soils is of great interest because an excess of dietary intake of some of these heavy metals might be deleterious to the health of the consumers (Page *et al*., 1981; Baath, 1989; Roads *et al*., 1989; Gerzabek and Ullah, 1990; Ullah *et al*., 1995). Kashem and Singh (1998) found that textile, tannery, dyeing and sulphuric acid producing industries increased the concentration of Cu, Mn, Ni, Pb, Cr, and Cd in the vicinity of industry in Dhaka, Bangladesh.

Nuruzzaman (1995) observed that the soils in tannery industrial sites contained higher amounts of Cr, Zn, Cu and Pb, which exceeded the toxic levels in soils. He also found high concentration of Zn, Hg, Cd and Mn in the battery industrial sites around Dhaka.

Chamon *et al. (*2005) and Alam (2006) observed that there were many chemical industries in and around Tejgaon area namely tannery, paper and pulps, textiles, carbides, pharmaceuticals, pesticides, distilleries etc. which discharged heavy metals like Cd, Pb, Cr, Hg, Zn, As and in a few cases Cu and Mn with their effluents and wastes. And, at present the underground water is not safe for drinking purpose because of heavy metal contamination.

2.2.4 *Remediation Technologies for Heavy Metals*

Industrialization and environmental pollution is a burning and most common issue all over the world. And at the same time, a huge amount of land had been contaminated and polluted by heavy metals and other environmental toxins. So, toxic metal remediation should be an urgent initiative to protect our polluted and degraded lands, or to reclaim our degraded lands, or to use our lands with desired purpose with no negative impact on crops, food chain and ultimately human health.

Soil remediation as the return of soil to a condition of ecological stability together with the establishment of plant communities it supports or supported to conditions prior to disturbance (Allen, 1998).The conventional technologies involved for the removal of metals from polluted soils by transportation to laboratories, soil washing with chemicals to remove metals and finally replacing the soil at its original location or disposing of it as hazardous waste (Francis *et al*., 1999). This decontamination strategy is an ex- situ approach and can be very expensive and damaging to the soil structure and ecology (Salt *et al*., 1995). Immobilization of heavy metals through the addition of lime (Krebs *et al*., 1999), phosphate (Ebbs *et al*., 1998) and calcium carbonate ($CaCO_3$) (Chen *et al*., 2000) have been also suggested as remediation technologies.

Many remediation technologies have been developed to treat soil, leachate, wastewater and ground-water contaminated by various pollutants, including *in situ* and *ex situ* methods in response to a growing need to address environmental contamination (Aboulroos *et al*., 2006). The conventional methods to remediate metal contaminated soils are soil flushing, solidification, stabilization, vitrification, thermal desorption, encapsulation (BIO-WISE, 2003) which can be used at highly contaminated sites but are not applicable to large areas. However, Raskin *et al*. (1996) recommend precipitation or flocculation followed by sedimentation, ion exchange, reverse osmosis and micro-filtration processes as remediation process. These remediation methods require high energy input and expensive machinery (Schnoor, 1997), and generally costly and have side effects (Raskin *et al*., 1997 and McGrath *et al*., 2001). At the same time they destroy soil structure and decrease soil productivity (Leumann *et al*., 1995).

For that reason, over the past decades, there has been increasing interest for the development of plant based remediation technologies which have the potential to be low-cost, low-impact and environmentally sound (Cunningham and Ow, 1996), a concept called "Phytoremediation".

2.2.4.1 *Phyto-remediation Techniques*

Phyto-remediation consists in mitigating pollutant concentration in contaminated soils, water or air, with plants able to contain, degrade or eliminate metals, pesticides, solvents, explosives, crude oil and its derivatives, and various other contaminants from the media that contain them (Web., 3). Phyto-remediation is an integrated multidisciplinary approach to clean up contaminated soils, which combines with the disciplines of plant physiology, soil chemistry and soil microbiology (Cunningham and Ow, 1996). In phyto-remediation, the roots of established plants absorb metal elements from the soil and translocate them to the above ground shoots where they accumulate. After sufficient plant growth and metal accumulation, the above ground portions of the plants are harvested and removed, resulting in the permanent removal of metals from the site (Nandakumar *et al.*, 1995).

Khan *et al*. (2004) has applied a number of contaminants in small scale field and/or laboratory for phytoremedation studies. They found that certain species of higher plants can accumulate very high concentrations of metals in their tissue without showing toxicity (Klassen *et al*., 2000; Bennett *et al*., 2003), or produce a large quantities of plant biomass (Ebbs *et al*., 1998), or have metal detoxifying mechanisms and/or high metal tolerant and accumulation capacity in their shoots, or have *in situ* inactivation or compartmentalization capacity into root vacuoles.

Phytoremediation of metals from soils has been successfully carried out at military sites, agricultural fields, industrial sites and mine trailing (Baňuelos, 2000; Winter Sydnor and Redente, 2002). According to Hooda (2007), phytoremediation is an emerging technology, which uses plants and their associated rhizospheric micro-organisms to remove pollutants from contaminated sites. This plant based technology is well accepted because of its environmental friendly, low costing and efficient technology especially for removing toxic metals.

The concept of using plants to clean up contaminated environments is not recent. About 300 years ago, plants were proposed for use in the treatment of wastewater (Hartman, 1975). At the end of the 19th century, *Thlaspi caerulescens* and *Viola calaminaria* were the first plant species documented to accumulate high levels of metals in leaves (Baumann, 1885). In 1935, Byers reported that plants of the genus Astragalus were capable of accumulating up to 0.6% Se in dry shoot biomass. One decade later, Minguzzi and Vergnano (1948) identified plants able to accumulate up to 1% Ni in shoots. More recently, Rascio (1977) reported that *Thlaspi caerulescens* is Zn tolerant and accumulating plant.

Chaney (1983) reintroduced and developed the idea of using plants to extract metals from contaminated soil. It was the first field trail conducted on Zn and Cd phytoextraction to investigate the biology of metal phytoextraction. Despite significant success, the understanding of the plant mechanisms that allow metal extraction was still emerging. In addition, relevant applied aspects, such as the effect of agronomic practices on metal removal by plants were largely unknown. Hyperaccumulator plant species do not only accumulate high levels of essential micronutrients, but also can absorb significant amounts of nonessential metals, such as Cd. This might be due to chemically analogous to different species (Chaney *et al*., 1994).

Metal tolerance is an indispensable property of plants. Plants evolved several effective mechanisms for tolerating high concentrations of metals in soil. In some species, tolerance is achieved by preventing toxic metal uptake into root cells. These plants, coined excluders, have little potential for metal extraction and such excluder is "Merlin" a commercial variety of red fescue (*Festuca rubra*), used to stabilize erosion- susceptible metal contaminated soils. A second group of plants are accumulators that do not prevent metals from entering the root. Accumulator species have evolved specific mechanism for detoxifying high metal level accumulated in the cells. These mechanisms allow bioaccumulation of extremely high concentration of metals. A third group of plants, termed indicators, show poor control over metal uptake and transport process (Raskin *et al*., 1994). And common non-accumulator plants have evolved several mechanisms to control the homeostasis of intracellular ions. Such mechanisms include regulation of ion influx (stimulation of transporter activity at low intracellular ion supply, and inhibition at high concentration), and extrusion of intracellular ions back into the external solution.

Phytormediation exploits plant's innate biological mechanisms for human benefit. So, for the remediation of toxic metal from soil and water, the following phytoremediation technologies can be adopted: i) Phytoextraction: the use of metal- accumulating plants to remove toxic metals from soil, ii) Phytostabilization: the use of plants to eliminate the bioavailability of toxic metals in soils, iii) Phyto-volatilization: evaporation of certain metals from aerial parts of the plant, and iv) Rhizofiltration: the use of plant roots to remove the toxic metals from polluted waters.

2.2.4.1.1 Phytoextraction:

The terms phytoremediation and phytoextraction are sometimes incorrectly used as synonymous, but phytoremediation is a concept, whereas phytoextraction is a specific clean-up technology (Prasad and Feritas, 2003). Certain plants called hyperaccumulators absorb usually large amounts of metals compared to other plants and the ambient metals concentration (Prabha *et al*., 2007). Metal phytoextraction based on metal-accumulating plants to transport and concentrate polluting metals from soil into the harvestable aboveground shoots (Salt *et al.,* 1998; Vassil *et al*., 1998). During the phytoextraction

procedure, plants cover the soil and erosion and leaching will thus be reduced. With successive cropping and harvesting, the levels of contaminants in the soil can be reduced (Vandenhove *et al.*, 2001).

The plant material can subsequently be used for nonfood purposes (e.g. wood, cardboard) or ashen, followed by disposal in a landfill or, in the case of valuable metals, the accumulated element can be recycled. The latter is termed as phytomining (Chaney *et al.*, 2000). Salt *et al.* (1995) reported that the costs involved in phytoextraction would be more than ten times less per hectare compared to conventional soil remediation techniques. Phytoextraction also has environmental benefits because it is considered a low impact technology. It has been known since the late 1800s that a special category of plants, the so called hyperaccumulators can accumulate extraordinary levels of metals. At present, at least 45 plant families are known to contain metal-accumulating species (Reeves and Baker, 2000). Such plants can accumulate As, Cu, Co, Cd, Mn, Ni, Se, Pb or Zn up to levels that are 100 to 1,000 times of those normally accumulated by plants grown under the same conditions (Baker *et al.*, 2000; Ma *et al.*, 2001). A number of these species are the members of Brassicaceae, including a species of Arobidopsis (*A. halleri*) which can hyperaccumulate Zn in its shoots (Reeves and Baker, 2000). Recently, *Sonchus asper* and *Corydalis pterygopetata* grown a lead -zinc mining area in China have been identified as heavy metal hyper-accumulators (Yanqun *et al.*, 2005).

According to Baker and Brooks (1989), hyper-accumulators should have a metal accumulation exceeding a threshold value of shoot metal concentration of 1% for Zn, Mn; 0.1% for Ni, Co, Cr, Cu, Pb and Al; 0.01% for Cd and Se or 0.001% for Hg of the dry weight shoot biomass. The time required for remediation depends on the type and extent of metal contamination, the duration of the growing season, and the efficiency of metal removal by plants, but it normally ranges from 1 to 20 years (Kumar *et al.*, 1995; Blaylock and Huang., 2000). This technique is suitable for remediating large areas of land contaminated at shallow depths with low to moderate levels of metal contaminants (Kumar *et al.*, 1995; Blaylock and Huang, 2000).

2.2.4.1.2 Phytostabilization:

Phytostabilization refers to the *in situ* or in place inactivation of pollutants, is primarily used for the remediation of soil, sediment and sludges (USPA, 2000). Phytostabilization of metals may employ plants to reduce leaching, runoff, and erosion via stabilization of soil by plant roots or root exudates may cause metal to precipitate, converting them to less bio-available form (Berti and Cunningham, 2000; Burken *et al.*, 2000; Kramer and Chardonnes, 2001). For phytostabilization of metals, a combination of trees and grasses work best. Fast-transpiring trees such as 'poplar' maintain an upward flow to prevent downward leaching, while grasses prevent wind erosion and lateral runoff with thin dense root system, Further, grasses do not accumulate as much metals in their shoots as dicot species, minimizing exposure of wild life to toxic elements (Pilon- Smits, 2005).

Phytostabilization can occur through the sorption, precipitation, complexation, or metal valance reduction. It is useful for the treatment of lead (Pb), as well as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn). Some of the advantages associated with this technology are that the disposal of hazardous material/ biomass is not required (USPA, 2000).

Phytostabilization uses certain plant species to immobilize contaminants in soil, through absorption and accumulation by roots, adsorption onto roots or precipitation within the root zone and physical stabilization of soils (Prabha *et al*., 2007). One way to facilitate such immobilization is by altering the physicochemical properties of the metal-soil complex for introducing a multipurpose anion, such as phosphate, that enhances metal adsorption via anion-induced negative charge and metal precipitation (Bolan *et al*., 2003). Phytostabilization also involves soil amendments to promote the formation of insoluble metal complexes that reduce biological availability and plant uptake, thus preventing metals from entering the food chain (Cunningham *et al*., 1997; Berti and Cunningham, 2000; Adriano *et al*., 2004).

Conesa *et al*. (2006) reported two plant species such as *Hyparrhenia hirta* and *Zygophyllum fabago*, that have naturally colonized some parts of mine tailing in South East-Spain, have been reported to tolerate high metal concentrations in their rhizo-spheres. These plant species do not take up high concentrations of metals, providing a good tool to achieve surface stabilization of tailings with low risk of affecting the food chain.

Phytostabilization is also called in place inactivation or phyto-restoration. It can be adapted to different sites with a variety of conditions (e.g., soil pH, salinity, soil texture, metal levels and contaminant types) through the careful selection of amendments, rates, and plants. Phytostabilization is relatively inexpensive or least expensive and may be an appropriate remediation choice at many types of sites (e.g., industrial sites, shooting ranges, smelting sites, mining areas and urban areas) (Berti and Cunningham, 2000).

2.2.4.1.3 Phytovolatilization:

 It means the use of plants to take up contaminants from the soil, transforming them into volatile forms and transpiring them into the atmosphere (USPA, 2000) as gas. Although, it works well for organics, this can be used for a few inorganic that can exist in volatile form i.e., Se, Hg and As (Rugh *et al*., 1996; Hansen *et al*., 1998). Among the aquatic species, rice, rabbit foot grass, Azolla and pickle weed are the best Se volatilizers (Hansen *et al*., 1998; Pilon-Smits *et al*., 1999; Lin *et al*., 2000; Zayad *et al*., 2000). Volatilization of Se involves assimilation of inorganic Se into the organic selenoaminoacids, selenocysteine (SeCys) and selenomethionine (SeMet). The latter can be methylated to form dimethylselenide (DMse), which is volatile (Terry *et al*., 2000). At last, volatilization completely removes the pollutant from the site as a gas, without need for plant harvesting and disposal. So, it is an appealing technology.

According to Brooks (1998), the release of volatile Se compounds from higher plants was first reported by Lewis *et al*. (1966). Terry *et al*. (1992) reported that members of the Brassicaceae are capable of releasing up to 40 gm Se ha^{-1} day^{-1} as various gaseous compounds. Phytovolatilization should be avoided for sites near population centers and at places with unique meteorological conditions that promote the rapid deposition of volatile compounds (Heaton *et al*., 1998). So, the consequences of releasing the metals to the atmosphere need to be considered carefully before adopting this method as a remediation tool.

2.2.4.1.4 Rhizofiltration:

This method of remediation is primarily used to remediate extracted ground water, surface water and wastewater with low contaminant concentrations (Ensley, 2000). In rhizofiltration, plant roots grown in water absorb, concentrate and precipitate toxic metals and organic chemicals from polluted effluents (Schmoger *et al*., 2000).

The plants can be used as filters in constructed wetlands (Lytle *et al*., 1998; Horne, 2000) or in a hydrophonic setup (Raskin *et al*., 1997), comprising a complex ecosystem of plants, microbes and sediment that together act as a biogeochemical filter, efficiently removing contaminants from wastewater (Dushenkov and Kapulnik, 2000; Negri and Hinchman, 2000). Constructed wetlands have been used for a wide range of inorganics including metals, Se, perchlorate, cyanide, nitrate and phosphate (Hansen *et al*., 1998; Horne, 2000; Nzengung and McCutcheon, 2003).

The advantages associated with rhizo-filtration are the ability to use both terrestrial and aquatic plants for either *in situ* and *ex situ* applications. Another advantage is that contaminants do not have to be translocated to the shoots. The species other than hyper-accumulators may be used. Terrestrial plants are preferred because they have a fibrous and much longer root system with increased amounts of root area (Raskin and Ensley, 2000). Sunflower (*Asteraceaea* spp.) has successfully been implemented for rhizofiltration at Chernobyl to remediate uranium contamination. Dushenkov *et al*. (1995) observed that the roots of many hydrophonically grown terrestrial plants such as Indian mustard (*B. Juncea*) and sunflower (*H. annus*) effectively removed the toxic metals like Cu, Cd, Cr, Ni, Pb and Zn from aqueous solution.

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Field Study

Due to lack of consciousness, disposal of solid wastes and effluents near the lands, ditches, ponds and lagoons from different kinds of industries is a common scenario all over Bangladesh. A DoE source said that about 1200 dyeing, tannery, chemicals, food processing and other industries are polluting the soils and water in and around Dhaka severely (Roy, 2009). Land shortage has forced farmers to use the fallow lands around industries that are within the reach of waste disposal. Such situation demands evaluation of the extent of soil and crop contamination by toxic heavy metals and other environmental toxins coming out of the industrial units. So, to protect our environment from pollution problem, wastewaters, soils and plant samples were collected from different industrially polluted areas in and around Dhaka during dry season between the years of 2009 - 2010.

3.1.1.1 *Sampling Sites of the Industrially Polluted areas in and Around Dhaka*

Considering the above statistical information and apprehending the severity of pollution, composite wastewaters, soils and plant samples were collected randomly from adjacent to different kinds of industrial plants under 10 industrial clusters in and around Dhaka. Each composite sample was prepared by collecting three representative samples of adjoining areas. And 35 wastewaters, 37 soils and 37 plant samples were collected randomly from those spots as well. A map of the region showing the locations of sampling sites have been presented in Figure- 3.1.

3.1.1.2 *Description of the Selected Industrial Clusters*

The details of ten selected industrial clusters from which wastewaters, soils and plant samples were collected have been described as follows:

1. Ashulia is located at the North-Western part of greater Dhaka district, where spinning, dyeing, textile, chemicals, steel and re-rolling mills, plastic and apparels are the major industries in that area.

2. Derma is situated at the eastern zone of Dhaka city, where steel and re-rolling mills, corrugated sheets, chemical industry, dyeing and textile mills, polythene and poly packs, tubes and pipes, food and beverage industries are mostly present.

3. Gazipur industrial area is located within the greater Dhaka district (now in Gazipur). It is about 18km north from the capital City Dhaka, consists of battery factories, dyeing units, textile mills, paint factories, tannery, chemical industries, pharmaceutical industries, steel and rerolling mills etc.
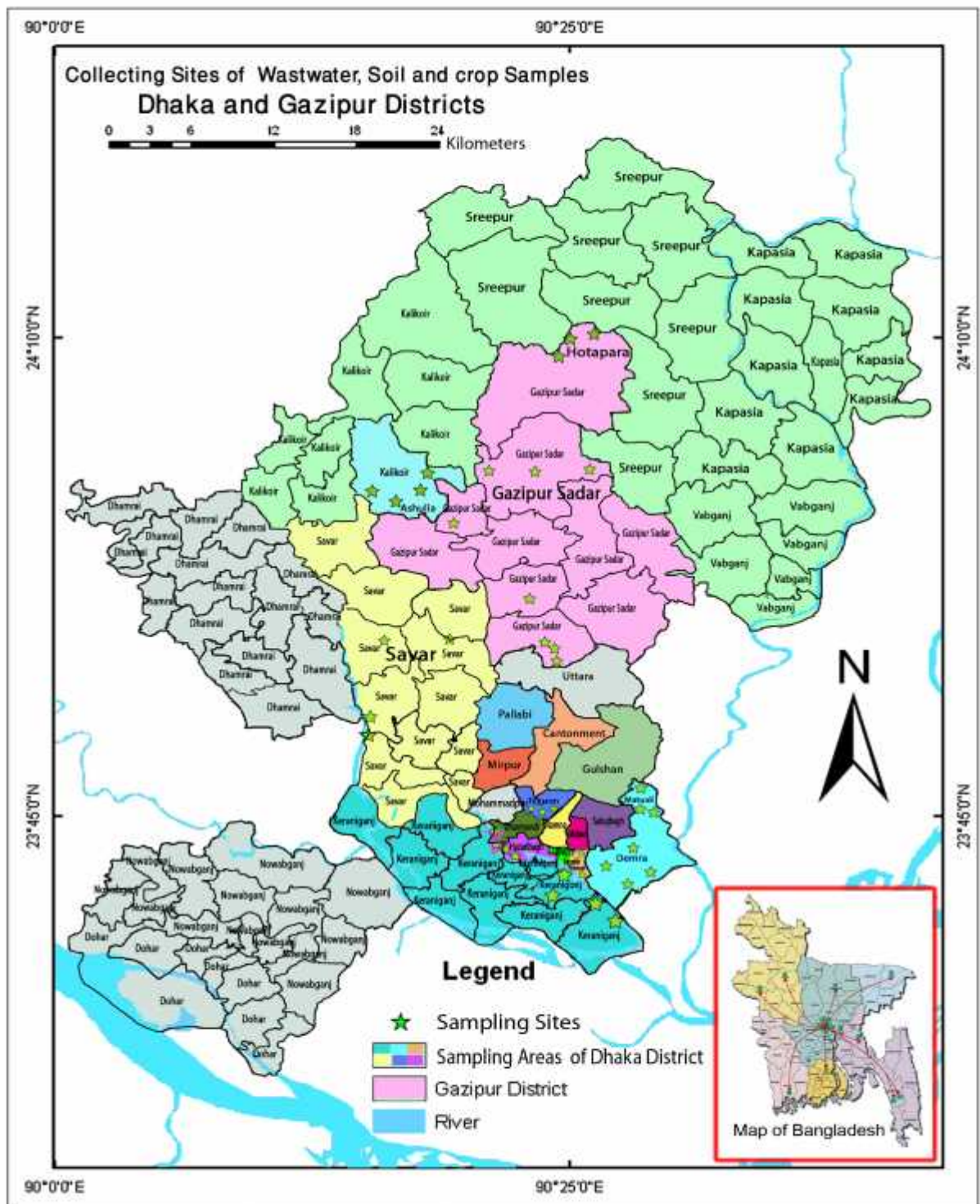
Figure- 3.1: Wastewaters, soils and plant samples collecting sites in and around Dhaka (Inset: Map of Bangladesh)

4. Hazaribagh tannery complex is situated on the bank of the Buriganga and within the Dhaka municipality area (WSW) of the city. The tannery factories are located inside the greater Dhaka flood protection embankment and it is the largest and worst polluted industrial area of Dhaka city. At Hazaribagh tannery area, about 198 tannery industries are situated and

in tannery industries various chemicals, dyes and preservatives are being used for soaking, fleshing, pickling, re-tanning and finishing of hides.

5. Hotapara is situated at northern part of Gazipur sadar, where mainly dyeing, spinning mills, food and beverage and apparels are present.

6. Keranigonj is situated at the south bank of Buriganga, which comprises mainly of steel mills, corrugated sheets, chemical industry, battery industry, textile, dyeing and food and beverage mills.

7. Matuail is situated at the eastern zone of Dhaka city, where steel and re-rolling mills, corrugated sheets, chemical industry, dyeing and textile mills, polythene and poly packs, food and beverage industries are mostly present.

8. Savar is situated at the north-west side of Dhaka city and comprises mostly of textile, dyeing, chemicals, food and beverage, pharmaceuticals, steel and re-rolling mills and spinning factories.

9. Shampur industrial area is situated at the south of Dhaka city and mostly metal industries such as electroplating, metal re-rolling mills etc., furniture, dyeing, food and beverage, and textile industries are located.

10. Tejgaon is the largest industrial zone within Dhaka influenced by sanitary, battery, soap, printing and dyeing, casting, electroplating, beverage factories, rubber and plastic, utensils, biscuits and some metal work industries. The sampling site is situated near Rampura, Tejgaon in Dhaka.

3.1.1.3 *Collection, Processing and Preservation of Wastewaters, Soils and Plant Samples*

3.1.1.3.1 Collection

Wastewaters, soils and plant samples were collected from different industrial areas in and around Dhaka following the sampling methods as described by APHA (2005) and Imamul Haq and Alam (2005).

Approximately 2 liters of wastewaters were collected from the nearby ditches of discharged effluents from different industries and was poured into plastic bottles, filtered through filter paper no. Whatman 1 and it was kept in a freeze at 4^0C temperature before analyzing different parameters.

The soil samples were collected from the adjacent lands of different industries in and around Dhaka from the upper 15 cm depth in polythene bags.

The existing plants such as Lal sak, Kalmi sak, Spinach, Grass and Rice were collected from different industrially polluted lands in and around Dhaka City from which soil samples were collected.

3.1.1.3.2 Processing and Preservation

Preservation procedure varied depending on the test to be performed. For the determination of DO, the collected water samples were poured into bottles and were treated with 2 ml of manganese sulphate solution ($MnSO_4$, $4H_2O$) followed by 2 ml of alkali-iodide azide reagents in the field. The bottles were then shaked to allow thorough mixing of the contents. The bottles were stoppered in such a way so that no air bubbles were left (APHA, 2005).

To determine the nitrate, nitrite, ammonium, phosphate, sulphate, chloride, bicarbonate and carbonates, the wastewater samples were preserved in 250 ml amber glass bottle. To stop the conversion of nitrite to either nitrate or ammonia by microbial action, the samples were temporarily preserved with 4 ml conc. H_2SO_4 acid and for phosphate determination; 1.25 ml of chloroform was added in the sample to reduce the microbial activities (APHA, 2005). All the bottles with samples were then placed in wooden boxes to avoid direct sun light and thus the samples were transported to laboratory and were kept in refrigerator at 4^0C till the analysis were done.

The collected soil samples were air dried by spreading on separate sheet of papers after it was transported to the laboratory. After air drying, the larger aggregates were broken gently by crushing in a wooden mortar. The crushed soils were passed through a 2.0 mm sieve. The sieved soils were then preserved in plastic containers with marking the name of the spots.

The collected plant samples were washed with distilled water to remove dust and soil particles and later the samples were dried in air. The samples were further oven dried at 70^0C for over 48 hours and then crushed with blender. The samples were stored in air-tight plastic bottles for further analysis.

Plate- 1 - 9 showing some of the contaminated sampling sites from which wastewaters, soils and plant samples were collected.

Plate- 1a (wastewaters) and 1b (agricultural land) near Aman Spinning Mills Ltd., Ashulia

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Plate- 2a (soils) and 2b (agricultural land) near I I Tube Mills Ltd., Demra, Dhaka

Plate- 3a (Haq battery) and 3b (dumping site at Meghna ghatt), Tongi, Gazipur

Plate- 4a and 4b (wastewater ditches) at Hazaribagh tannery area, Dhaka

Plate- 5a (wastewater canal) and 5b (agricultural land) near Givensee Groups at Hotapara, Gazipur

Plate- 6a (wastewaters) and 6b (lands) at Keranigonj- 3 near battery industries Dhaka

Plate- 7a (wastewater ditch) and 7b (lands) at Matuail industrial area, Dhaka

Plate- 8a (wastewater canal and land near Doel group, Savar) and 8b (soils near steel mills at Shampur, Dhaka)

Plate- 9a (wastewaters near dyeing industry at Shampur, Dhaka) and 9b (wastewaters at Tejgaon industrial areas, Dhaka)

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3.1.2 Green House Study

Pot experiments were conducted in the Green House of the Department of Soil, Water and Environment, University of Dhaka, from December 2010 to May 2011. The experiments were conducted with six different varieties of rice crops (BR- 15, BR- 16, BR-19, Brridhan-28, Brridhan-29 and Brridhan- 45) and three leafy vegetables (Lal sak, Kalmi sak and Spinach) and a Jumboo grass in completely randomized design with three replications.

3.1.2.1 *Collection and Preparation of Soils, Rice seedlings, Vegetable seeds and Fertilizers*

Collection of soil samples: Soil samples were collected from the village Sakrauri, Gazipur. Bulk soil samples representing 0-15 cm depth were collected from the agricultural field by pit and core method with the help of a soil auger and spade.

Soil sample preparation: Collected soils were air-dried for several days in the Green House of the Department of Soil, Water and Environment, University of Dhaka, avoiding direct sunlight and dusts. After air-dried, a portion of the larger and massive aggregates were broken by crushing with a wooden hammer and then mixed thoroughly to make it a representative composite sample. Dry roots, grasses and other particulate materials were discarded from the soils and were used for pot experiment.

A portion of the crushed soils was passed through a 2.0 mm sieve. The sieved soils were then kept in a plastic container for physical and chemical analysis.

Collection of fertilizers: All fertilizers (Urea, TSP, MP and Gypsum) were procured from the sale centre of Bangladesh Agricultural Development Corporation (BADC), Dhaka.

Collection of rice seedlings: 42 days old rice seedling of BR-15, BR-16, BR-19, Brridhan-28, Brridhan- 29 and Brridhan- 45 were collected from the seedbed of Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur.

Collection of crop seeds: The BADC certified seeds of three types of leafy vegetables and a grass crop such as Spinach (*Spinach oleracea*), Lal sak (*Amaranthus curentus*), Kalmi sak (*Ipomoea aquatica*) and Grass (Jumboo grass) were collected from commercial seed store.

3.1.2.2 *Properties of Collected Soils for Pot Experiment*

The collected soil belongs to Bhatpara Series. The topography was upper slope of gentle undulation, imperfect and externally rapid, internally impeded and above flood level drainage condition. The common land use of the series was aus paddy- fallow. The analytical results of the soils as collected for pot experiment have been presented in Table- 3.1.

Table- 3.1: Analytical results of soils collected for pot experiment

No.	Parameters	Results
1	**Texture**	Silty clay loam
2	**pH**	5.64
3	**EC** (μS/cm)	30
4	**Moisture (%)**	0.51
5	**Organic C (%)**	1.04
6	**Total N (%)**	0.14
7	**Total P (%)**	0.05
8	**Total Ca** (meq/100 gm soil)	1.33
9	**Total Mg** (meq/100 gm of soil)	0.729
10	**Total K (%)**	0.25
11	**Exchangeable- K** (meq/100 gm of soil)	0.06
12	**CEC** (C moles/ kg soil)	2.94
13	**Pb** (mg/kg)	1.30
14	**Zn** (mg/kg)	30.0
15	**Cu** (mg/kg)	1.0
16	**Ni** (mg/kg)	0.50
17	**Cd** (mg/kg)	0.11

3.1.2.3 *Setup of Experiments and Treatment Combinations of Metals*

3.1.2.3.1 Experiment- 1a and 1b (Effect of different levels of Pb and Cd alone on Brridhan- 28 rice as a test crop)

7 kg of air dried soil samples were taken in 10 liter sized plastic pot. Brridhan- 28 rice variety was selected as test crop for the experiment. A total of eight treatments were chosen with three replications of each. Basal dose of fertilizers as recommended by BRRI was applied in each pot. The recommended doses were urea 245 kg/ha, TSP 125 kg/ha, MP 150 kg/ha and gypsum 72 kg/ha. The date of seedling transplantation was 25. 12. 2010 and the date of crop harvest was 03. 05. 2011. Table- 3.2 indicates the treatment denotations and the corresponding heavy metal doses applied on Brridhan- 28 rice. And, setup of experiments 1a and 1b have been presented in plate- 10.

Table- 3.2: Treatment Levels of Pb and Cd on Brridhan- 28 rice

Experiment – 1a		Experiment – 1b	
Treatment denotation	Pb as $Pb(NO_3)_2$ (mg/kg)	Treatment denotation	Cd as $3Cd\,SO_4,\,8H_2O$ (mg/kg)
T0	Control	**T0**	Control
T1	100	**T1**	03
T2	125	**T2**	05
T3	150	**T3**	07
T4	175	**T4**	09
T5	200	**T5**	15
T6	250	**T6**	30
T7	300	**T7**	60
T8	350	**T8**	90

Plate- 10: Setup of Experiment 1a and 1b with Brridhan- 28 Rice (Green House, Department of Soil, Water and Environment, DU)

3.1.2.3.2 Experiment- 2a and 2b (Effect of 200 mg/kg Pb and 7 mg/kg Cd on five different rice varieties as test crops)

7 kg air dried soil samples were taken in 10 liter sized plastic pot. BR- 15, BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45 varieties were selected as test crops for the experiment. 200 mg/kg Pb and 7 mg/kg Cd treatments were chosen with three replications of each. Basal dose of fertilizers as recommended by BRRI was applied in each pot. The recommended doses were urea 245 kg/ha, TSP 125 kg/ha, MP 150 kg/ha and gypsum 72 kg/ha. The date of seedlings transplantation was 20. 01. 2011 and the date of crop harvesting was 10. 05. 2011. Table- 3.3 indicates the variety denotations and the doses Pb and Cd applied on five different varieties of rice. And, setup of experiments 2a and 2b have been presented in plate- 11.

Table- 3.3: Treatment Combinations of Pb and Cd on Five Different Rice Varieties

No.	Experiment – 2a		Experiment – 2b	
	Denotation of the rice varieties	Treatments Pb as Pb $(NO_3)_2$ (mg/kg)	Denotation of the rice varieties	Treatments Cd as $3CdSO_4, 8H_2O$ (mg/kg)
1	V1 (BR-16)	BR - 16-control BR - 16 + Pb 200	V1 (BR - 16)	BR-16- Control BR-16 + Cd 7
2	V2 (BR-15)	BR-15- Control BR-15 + Pb 200	V2 (BR - 15)	BR-15- Control BR-15 + Cd 7
3	V3(BR-19)	BR-19- Control BR-19 + Pb 200	V3(BR - 19)	BR-19- Control BR-19 + Cd 7
4	V4 (Brridhan-45)	Brridhan- 45- Control Brridhan- 45 + Pb 200	V4 (Brridhan - 45)	Brridhan- 45- Control Brridhan- 45 + Cd 7
5	V5 (Brridhan-29)	Brridhan- 29- Control Brridhan- 29 + Pb 200	V5 (Brridhan - 29)	Brridhan- 29- Control Brridhan- 29 + Cd 7

Plate-11: Setup of experiments 2a and 2b with five different varieties of rice cultivars (In the Green house, Dept. of Soil, Water and Environment, DU)

3.1.2.3.3 Experiment- 3a and 3b (Effect of 200 mg/kg Pb and 15 mg/kg Cd on different leafy vegetables and grass as test crops)

7 kg soils air dried soil samples were taken in 10 kg sized mud pot. Lal sak, Kalmi sak, Grass and Spinach were selected as test crops for the experiment. 200 mg/kg Pb and 15 mg/kg Cd treatments were chosen with three replications of each. Basal dose of fertilizer recommended by BARI was applied in each pot for four different vegetables and grass. The date of sowing was 30.12. 2010 and the date of harvesting of the crops was 04. 03. 2011. Table- 3.4 indicates the denotations of vegetables and grass and the doses of Pb and Cd applied. And, setup of experiments 3a and 3b have been presented in plate- 12.

Table- 3.4: Treatment Combinations of Pb and Cd on Different Vegetables and Grass

No.	Denotations	Experiment - 3a		Experiment - 3b	
			Treatments		**Treatments**
		Types of crops	**Pb as Pb (NO₃)₂ (mg/kg)**	**Types of crops**	**Cd as 3Cd SO₄, 8H₂O, (mg/kg)**
1	V1	**Lal sak** (*Amaranthus curentus*)	Lal sak - Control Lal sak + Pb 200	**Lal sak** (*Amaranthus curentus*)	Lal sak - Control Lal sak + Cd 15
2	V2	**Kalmi sak** (*Ipomoea aquatica*)	Kalmi sak- Control Kalmi sak + Pb 200	**Kalmi sak** (*Ipomoea aquatica*)	Kalmi sak - Control Kalmi sak + Cd 15
3	V3	**Grass** (Jumboo grass)	Grass - Control Grass + Pb 200	**Grass** (Jumboo grass)	Grass - Control Grass + Cd 15
4	V4	**Spinach** (*Spinach oleracea*)	Spinach – Control Spinach + Pb 200	**Spinach** (*Spinach oleracea*)	Spinach - Control Spinach + Cd 15

Plate- 12: **Setup of experiments 3a and 3b with three different leafy vegetables and a grass crop (In the Green house, Dept. of Soil, Water a and Environment, DU)**

3.1.2.4 *Procedures of Pot Experiments*

Preparation of pots: Pots were well washed and dried in sunlight. Seven kilogram of air dried composite soil was taken in 10 kg sized plastic and mud pot. The soils were previously pulverized and mixed well with proper doses of fertilizers as per recommendation of the Fertilizer Recommendation Guide (BARC, 1997).

Marking of pots: Every pot was marked in accordance with the treatment and variety with a marking pen.

Experimental plants: For greenhouse experiment, six varieties of rice and three leafy vegetables and a grass crop were grown on soils mixed with different doses of Pb $(NO_3)_2$ and $3Cd\ SO_4, 8H_2O$ except control to investigate the effects of Pb and Cd on nutrient uptake, heavy metal contents and on the growth and yield of rice, leafy vegetables and grass crops.

Selection of seedlings and seeds: Only the healthy, plump, large and uniform sized seedlings and seeds were selected for transplanting/sowing.

Irrigation of pots: The amount of water lost through evaporation and transpiration was supplemented through daily application of tap water in the evening. In the case of rice plants, the water content of the soil was maintained at 3 cm above the soil surface throughout the growing period and in the case of vegetables and grass, water was added to the pots to the extent to maintain normal growth of the crops. The amounts and frequencies of water application were different for different crops.

Seedlings transplantation: For rice crops, three seedlings of 42 days old per hill and five hills per pot were transplanted. For vegetables and grass, the seeds were sown by spreading them over the surface of the pot soils. Then the seeds were covered by a thin layer of soil and the pots were covered by paper for germination.

Spacing and thickening: For rice plants, the space maintained between one hills to another was 10 cm and from one pot to another was 30 cm. For vegetable crops, after 15 days of germination, the seedlings were thinned keeping few seedlings in each pot. Besides, a knife was used to loose the soils at a regular interval of seven days.

Weeding: Weeds were controlled by up-rooting manually. The roots of the uprooted weeds were kept into respective pot, so that, no nutrient could be lost with the roots.

Control of pest, disease and rodents: Insecticide Malathion 57 EC (liquid) was sprayed twice during growing season to control cutworms according to the requirement. Malathion was applied at a dilution rate 1:1600. Lanirat was placed beneath the pot to control rodents during the growing period.

Harvesting: The straw and grain of rice crops were separated and collected properly. The roots of rice crops were washed with tap water and the fresh weight of the straw of the rice plant and grains were recorded.

Spinach, Kalmi sak, Lal sak and Grass were harvested after 70 days of sowing. The roots were washed with tap water to remove the soil materials from the root surfaces and the fresh weight of the straw of the vegetables and grass were recorded.

Collection and preservation of plant samples: The dusts of the collected straw, roots and grains were cleaned properly with tissue paper to remove dusts. The collected straw and roots of rice crops were initially air-dried in the laboratory and finally oven-dried at 70^0 C for 48 hours then weighed and ground and stored in plastic pots for chemical analysis. The grain samples were dried in air and also stored in plastic bottle for chemical analysis.

The collected straw and roots of leafy vegetables and grass were initially air-dried in the laboratory and finally oven-dried at 70^0 C for 48 hours then weighed and ground and stored in plastic pots for chemical analysis.

3.1.2.5 *Data Collection*

The following data were collected throughout the growing period:

1. Fresh weight of the straw/pot of rice

2. Dry weight of the straw/pot of rice

3. Dry weight of the grains/pot of rice

4. Fresh weight of the straw/pot of vegetables and grass

5. Dry weight of the straw/pot of vegetables and grass

3.2 Methods

3.2.1 *Wastewater Analysis: Physical, Chemical, Cationic and Heavy Metals*

3.2.1.1 Hydrogen ion concentration (pH): The pH of wastewater was measured by glass electrode digital pH meter (Model: HANNA Instrument, HI 98107) (Jackson, 1962).

3.2.1.2 Electrical conductivity (EC): The EC of wastewater samples was determined directly in the laboratory by EC meter (Model: HANNA Instrument, HI 8633) in µS/cm at 25^0 C (Jackson, 1962).

3.2.1.3 Conductivity: The conductivity of wastewater samples was directly determined in the laboratory by conductivity meter (Model: HANNA Instrument). The result was recorded as µS/cm.

3.2.1.4 Turbidity: The turbidity of wastewater samples was determined by using turbidity meter (Model: HANNA Instruments, HI- 93703 micro-process). The result was recorded as NTU following APHA (2005).

3.2.1.5 Dissolved Oxygen (DO): The dissolved oxygen of wastewater samples was determined by DO meter (Model: HANNA Instrument, HI- 363) following APHA (2005).

3.2.1.6 Total dissolved solids (TDS): The total dissolved solid of wastewaters was determined in the laboratory by TDS meter (Model: HANNA Instrument, HI 98302) (Todd, 1980).

3.2.1.7 Nitrogen

i. Nitrate -N: Nitrate -N of the wastewaters was determined directly by cadmium reduction method with a colorimeter (Model: HACH, DR/890) following APHA (2005). The result was recorded as mg/L.

ii. Ammonium -N: Ammonium -N of the wastewaters was determined by Diazotization method with a colorimeter (Model: HACH, DR/890) by following APHA (2005). The result was recorded as mg/L.

iii. Nitrite -N: Nitrite-N of the wastewaters was determined by salicylate method with a colorimeter (Model: HACH, DR/890) following APHA (2005). The result was recorded as μg/L.

3.2.1.8 Sulphate: The sulphate content of the wastewater samples was determined by $BaCl_2$ turbidimetric method (Hunt, 1981). The intensity of the color was measured in a spectrophotometer (Model: Jenway 6100) at 420 nm of wavelength.

3.2.1.9 Bicarbonate: The bicarbonate content of the wastewater samples was determined volumetrically following Jackson (1962) and APHA (2005). The result was recorded as mg/L.

3.2.1.10 Carbonate: The carbonate content of the wastewater samples was determined volumetrically following Jackson (1962) and APHA (2005). The result was recorded as mg/L.

3.2.1.11 Phosphate: Phosphate content of the wastewater samples was determined by ascorbic acid blue color method (Jackson, 1962). The intensity of the color was recorded in a Spectrophotometer (Model: Jenway 6100) at 670 nm of wavelength by stannous chloride reduction method (APHA, 2005), using ultra-violet spectro-photometer (APHA, 2005). The result was recorded as mg/L.

3.2.1.12 Chloride: The chloride of the wastewater samples was determined by Mohr volumetric method (Jackson, 1962). The result was recorded as mg/L.

3.2.1.13 Sodium and Potassium: Na and K of the wastewater samples were determined by using Flame Emission Spectrophotometer. The reading was taken in a flame photometer (Model: Jencons PEP 7) at 589 and 769 nm of wave length respectively (Jackson, 1962).

3.2.1.14 Calcium and Magnesium: Ca and Mg of the wastewater samples were determined by Atomic Absorption Spectro-photometer (Model: VARIAN- 220).

3.2.1.15 Zinc, Copper, Nickel, Lead and Cadmium: Zn, Cu, Ni, Pb and Cd of the wastewater samples were determined by Atomic Absorption Spectrophotometer (Model: VARIAN- 220) following calibration of the equipment for every l0 ml sample was include a certified reference material (CRM) to insure QA/QC.

3.2.2 *Soil Sample Analysis: Physical and Chemical*
3.2.2.1 Physical*:*

3.2.2.1.1 Moisture percentage: The moisture percentage of the collected soil samples was determined by drying a known amount of soil in an electrical oven at 105^0C for 24 hours until constant weight was obtained and the moisture percentage was calculated from the loss of moisture from the sample as described by Black (1965a).

3.2.2.1.2 Particle size analysis: The particle size analysis of the soil was carried out by Hydrometer method as described by Black (1965a) and the textural class was determined from Marshall's triangular coordinates as devised by the United States Department of Agriculture (USDA, 1951).

3.2.2.2 Physico-chemical:

3.2.2.2.1 Soil reaction (pH): Soil pH was determined electrochemically with the help of glass electrode pH meter (Model: Senso-Direct pH 200) as suggested by Jackson (1962). The ratio of soil to water was 1: 2.5.

3.2.2.2.2 Electrical conductivity (EC): The electrical conductivity of the soil was measured at a soil : water ratio of 1: 5 by an EC meter as described by USSL Staff (1954).

3.2.2.2.3 Organic carbon: The organic carbon was determined volumetrically by wet-oxidation method (Walkley and Black, 1934).

3.2.2.2.4 Total nitrogen: The total nitrogen of the soil was determined by Micro Kjeldahl's method following H_2SO_4 acid digestion as suggested by Jackson (1962).

3.2.2.2.5 Total phosphorus: The total phosphorus of soil was determined colorimetrically in the HNO_3 : HC1 (1 : 3) digestion (Blum *et al*., 1996) using a spectrophotometer after developing the yellow color with vanadomolybdate as described by Jackson (1962). The intensity of the yellow color was measured at 470 nm wavelength.

3.2.2.2.6 Cation exchange capacity (CEC): The CEC of soils was determined by extracting the soils with 1N NH_4Ac (pH =7.0) solution followed by replacing of ammonium in the exchange complex by 1N KC1 (pH 7.0). The displaced ammonium (NH_4^+) was distilled with 40% NaOH and ammonia (NH_3) evolved was absorbed in 2% boric acid containing mixed indicator. The ammonia (NH_3) absorbed was titrated with a standard N/10 H_2SO_4 acid (Black, 1965b).

3.2.2.2.7 Some Cations and Heavy Metals (Na, K, Ca, Mg, Zn, Cu, Ni, Pb and Cd): The total Na, K, Ca, Mg, Zn, Cu, Ni, Pb and Cd contents of soil was obtained by digesting the soil sample with the HNO_3 : HC1 acid mixture (1 : 3) (Blum *et al*., 1996). This aqua regia decomposes nearly all complexes forming soil particles (clay minerals, organic substance, oxide etc.), through which all the ions are brought into solution and can be measured quantitatively.

Na and K were determined by Gallenkamp Flame photometer analyzer at 589 nm and 767 nm respectively (Jackson, 1962).

Other metals (Ca, Mg, Zn, Cu, Ni, Pb and Cd) were measured in the digested soil samples by using Atomic Absorption Spectrophotometer (VARIAN- 220) (Jackson, 1962).

3.2.3 *Plant Sample Analysis: Chemical*

3.2.3.1 Total N:

Plant nitrogen (straw, grains and roots) was determined by Micro-Kjeldahl's method following H_2SO_4 acid digestion and steam distillation with 40% NaOH. Ammonia evolved was collected in boric acid containing mixed indicator and determined titrimetrically with a standard N/100 H_2SO_4 (Jackson, 1962).

3.2.3.2 Phosphorus, Some Cations and Heavy Metals:

Total P, Na, K, Ca, Mg, Zn, Cu, Ni, Pb and Cd: After wet oxidation with HNO_3 : $HClO_4$ (5:1) acid mixture (Perkin-Elmer, 1976), the total contents of P, Na, K, Ca, Mg, Zn, Cu, Ni, Pb and Cd in grains, straw and roots were determined by following the procedure as described in 3.2.2 for total soil analysis.

3.2.3.3 Transfer co-efficients (TC) of heavy metals

The transfer co-efficients were calculated by the following formulae, (TC) = Metal concentrations in plants part / Amounts of metal applied

3.2.4 *Statistical Analysis:*

 The results of the experiment were statistically evaluated in computer with SPSS version-16 and MSTAT system in the form of Duncan's Multiple Range Test (DMRT), co-efficient of variation (CV) and paired samples T- test.

4. RESULTS AND DISCUSSION

4.1 Field Study: (Polluted Wastewaters, Soils and Crop Samples):

Field study include the analytical results of the wastewaters, soils and crop samples collected from different industrial clusters in and around Dhaka.

4.1.1 Polluted Wastewaters (Physico-Chemical Properties):

Analytical results of the physical and chemical properties of the wastewaters collected from different industrially contaminated areas in and around Dhaka are presented in Table- 4.1 and their mean values and standard deviation (SD) are presented in Appen.Table- 1, 2 and 3.

4.1.1.1. *Hydrogen-ion Concentration (pH)*

Hydrogen ion concentration is one of the most important characteristics of water quality. Water may be acidic, neutral or alkaline in reaction. Water pH influences the other properties of waterbodies, activities of organisms and potency of toxic substances present in aquatic environment (Rouse, 1979).

 pH of the wastewaters in and around Dhaka was measured but the differences were observed among different industrial plants and locations. But, in most cases, the pH was found around neutral or within the permissible limit (6.5-8.5) of WHO for drinking water, but in few sites it was found highly acidic or alkaline in reaction. In the studied areas, pH of the wastewaters ranged from 3.1 at Demra- 3 near I I Tubes Mills Ltd. to 12.2 at Gazipur- 5 near Haq Battery (Table- 4.1). The mean values ranged from 6.18 at Keranigonj to 9.05 at Matuail and the SD ranged from ±0.06 at Tejgaon to ±3.09 at Demra (Appen.Table - 1).

 The lowest (extremely acidic) pH value (3.1) was found in the wastewaters at Demra- 3 near I I Tubes Mills Ltd. In I I Tubes Mills Ltd., GI, MS and SS steel and sanitary tubes and pipes were manufactured by galvanizing and electroplating processes, where they immerse and wash the iron tubes with concentrated HNO_3 and HCl acid to clean the dusts and rusts of the tubes and pipes before galvanization named aciding process. Those acids might be the main source to make the pH of the wastewaters extremely acid at Demra- 3. According to Khopkar (2008), steel and electroplating bath industrial wastes and effluents are acidic in nature and contain toxic metals, cyanides etc. On the other hand, the effluents of I I Tubes Mills Ltd. contained substantial amounts of Fe^{3+} and Zn^{2+} and during hydrolysis they might produce huge amounts of H^+ ions, which also might ultimately contribute to form strong acid in the wastewaters at that location. Moreover, HNO_3 acid, the byproduct of Zn $(NO_3)_2$, which was used as electrolyte in electroplating process in I I tube mills that might be another reason in the lowering of pH of the wastewaters at Demra- 3. The results were in agreement with Wuana and Okieimen (2011).

Table- 4.1: Analytical Results of Some Physical and Chemical Parameters of Wastewaters Collected from Different Industrial Areas in and Around Dhaka

No.	Locations	pH	EC (μS/cm)	Conductivity (μS/cm)	Turbidity (NTU)	TDS (mg/L)	DO (mg/L)	NO$_2^-$ - N (μg/L)	NO$_3^-$ - N (mg/L)	NH$_4^+$ - N (mg/L)	SO$_4^{2-}$ (mg/L)	HCO$_3^-$ (mg/L)	CO$_3^{2-}$ (mg/L)	Total Alkalinity (mg/L)	PO$_4^{3-}$ (mg/L)	Cl$^-$ (mg/L)
1	**Ashulia-1** (Shariar Fabric)	7.1	802	955	38	701	1.8	120	12	35	18	259	0	212.4	18	426
2	**Asulia-2** (Horizon Group)	7.4	865	989	19	730	1.0	350	8	10	200	390	0	319.8	16	284
3	**Asulia-3** (Aman Spinning)	8.5	1205	1335	241	951	0.8	540	13	6	150	389	250	736.5	12	533
4	**Ashulia- 4**(Near Turag R.)	7.8	110	220	7	79	2.6	30	0.9	0.5	5	90	0	73.8	3	107
5	**Demra-1** (Apollo I C S M L)	7.1	520	620	129	437	0.7	110	9	3	132	275	0	225.5	22	64
6	**Demra-2** (J Steel M Ltd**.**)	9.2	1132	1250	41	875	0.7	250	5	4	15	854	340	1268.1	18	256
7	**Demra-3** (I I Tubes M Ltd.)	3.1	1342	1407	26	984	1.7	153	308	45	3	0	0	0.0	28	107
8	**Gazipur-1** (Konabari I. A, T)	7.8	502	677	61	730	1.3	204	11	15	55	488	0	400.2	36	224
9	**Gazipur-2** (Apex Tannery, T)	8.1	823	956	157	480	0.5	663	8	5	190	477	0	391.1	34	199
10	**Gazipur-3** (BISIC, T.)	7.8	1150	1278	52	900	1.2	408	10	8	490	305	0	250.1	26	128
11	**Gazipur-4** (Metrocem SML.)	7.4	652	777	100	450	0.8	120	3	7	5	397	0	325.5	14	213
12	**Gazipur-5** (H Battery, T**.**)	12.2	1120	1297	81	909	0.9	207	7	4	110	0	610	1018.7	66	178
13	**Gazipur-6** (Mail Bazar, T.)	7.5	793	899	17	640	2.0	408	5	9	10	346	0	283.7	28	224
14	**Gazipur-7** (Meghna Ghat., T.)	10.1	992	1150	120	805	0.7	261	13	2	90	252	470	991.5	34	96
15	**Gazipur-8** (S S St. M Ltd., T.)	7.7	590	640	99	455	0.7	153	9	8	60	671	0	550.2	14	199
16	**Hazaribagh-1** (H.Tannery)	7.4	4500	5610	131	3929	0.2	1860	130	205	677	440	0	360.8	64	3509
17	**Hazaribagh-2** (H.Tannery)	8.1	5500	5703	616	3999	0.0	1950	145	230	780	490	0	401.8	75	5501
18	**Hotapara-1** (Givensee G.)	7.5	947	1100	353	770	0.7	200	25	13	421	488	0	400.2	23	538
19	**Hotapara-2** (Givensee G.)	7.1	746	855	100	600	1.0	150	8	10	350	427	0	350.1	19	474
20	**Hotapara-3** (Givensee G.)	7.25	810	908	290	630	0.9	160	14	16	370	455	0	373.1	20	490
21	**Keranigonj-1** (M S M L)	7.5	455	512	12	363	4.5	100	2	2	50	120	0	98.4	2	71
22	**Keranigonj-2** (Dyeing Ind.)	7.1	400	492	16	369	4.4	150	14	1	18	265	0	217.3	38	142
23	**Keraniganj-3** (Battery Ind.)	3.5	5771	5910	69	4139	1.1	0	8	0	7599	0	0	0.0	1	20
24	**Keraniganj-4** (M V C L)	6.6	232	342	35	247	1.4	95	7.5	4	150	90	0	73.8	6	180
25	**Matuail-1** (A S M L)	8.85	321	501	14	351	1.9	133	5	3.5	44	214	350	760.0	12	208
26	**Matuail-2** (Dyeing Ind.)	10.2	2310	2533	30	1750	1.6	1560	24	9	120	95	450	829.4	95	710
27	**Matuail-3** (D SM L)	8.1	550	677	11	474	2.1	120	4	7	210	301	0	246.8	15	350
28	**Savar-1** (Doel Groups)	8.7	1292	1411	30	990	1.9	150	18	13	900	718	170	705.6	16	228
29	**Savar-2**(Ernlima Yarn)	6.9	512	677	18	492	1.5	121	23	22	100	359	0	294.4	18	189
30	**Shampur-1** (S S R M Ltd.)	8.3	771	897	12	630	2.2	200	3	2	30	480	50	477.1	12	370
31	**Shampur-2** (Dyeing Ind.)	8.8	1031	1134	34	801	1.7	140	21	6	270	520	70	543.3	51	400
32	**Shampur-3** (K S M L.)	8.1	1100	1198	12	844	2.2	250	9	5	301	440	30	410.9	10	354
33	**Tejgaon-1** (Industrial A.)	8.2	800	897	5	640	3.4	26	5	2	46	300	40	279.4	18	305
34	**Tejgaon-2** (Industrial A.)	8.2	750	844	6	593	3.3	20	2	4	36	305	20	283.4	14	142
35	**Tejgaon-3** (Industrial A.)	8.1	679	779	6	570	3.3	60	6	5	34	339	0	278.0	15	105

Similarly, the extremely low pH value was also found in the wastewaters at Keranigonj- 3 near battery industry, where concentrated H_2SO_4 was directly used as electrolyte in manufacturing lead-acid storage batteries. But, the pH at Shampur- 3 near metal industry was also found slightly acidic. The result was in agreement with Khopkar (2008). The highest pH (12.20) value was observed at Gazipur- 5 near Haq Battery, where alkaline batteries were manufactured. And, for the production of alkaline battery, KOH was used as an alkaline electrolyte, which might be responsible to make the wastewaters markedly alkaline.

At Hazaribagh tannery- 1and 2, the pH was found 7.4 and 8.1, respectively. The result was in accordance with the finding of Karim *et al*. (2013). However, pH at Matuail- 2 (10.20) near dyeing industry and Gazipur- 7 (10.10) near the dumping site was also found alkaline, where chemicals, alkaline battery and textile wastes and their effluents were discharged. And, the pH at Demra- 2 (9.2) near Jahir Steel and Rerolling Mills, Matuail- 1(8.85) and Shampur-2(8.80) was found slightly higher than the permissible limit. For the purification of iron ores and washing and cleaning of steel foundry, calcium carbonate and other alkali materials were being used. Khopkar (2008) reported that the pH of steel foundry effluents was 8.5. On the other hand, the highest mean pH was found at Matuail (9.05) followed by Gazipur (8.57) and Shampur, where textile dyeing and metal industries were the main industrial plants at those industrial clusters. And by interconnecting canals textile dyeing industrial effluents mixing with the nearby industrial wastewaters, which might be associated with the rise in pH at different locations of the surveyed areas. Khopkar (2008) reported that pH of textile industrial effluents ranged from 7.0 to 11.8. In addition, Sultana *et al*. (2009) revealed that textile wastewaters composed of chemicals such as NaOCl, NaOH, Na_2SiO_3, surfactants and sodium phosphate and contributed high pH. The similar findings were also reported by Jashimuddin (1993), Alam (1994) and Ahmed *et al*. (2011). According to WHO the normal and tolerable pH range is in between 6.5 to 8.5 for drinking water.

Williams (1964) and Sharma *et al*. (1982) reported that the industrial or municipal waste materials had a significant role in increasing or decreasing the pH of the adjacent water body. Karim *et al*. (2013) revealed that tannery effluent had a pH value of approximately 8.0 and a very high conductivity. On the other hand, Ullah *et al*. (1995) and Islam *et al*. (2002) observed high pH values in some canals and rivers around Dhaka city, which were influenced by soap, battery, dyeing, tannery, welding, ceramics, pharmaceuticals and many other factories.

4.1.1.2 *Electrical conductivity (EC)*

Electrical conductivity is usually used for indicating the total concentrations of the ionized constitutions of water. It is closely related to the sum of the cations or anions as determined chemically and it is usually correlates closely with TDS (Rouse, 1979).

Electrical conductivity of wastewaters varied remarkably among the sampling sites of different industrial plants in and around Dhaka. In the studied areas, EC ranged from 232

µS/cm at Keranigonj- 4 to 5771 µS/cm at Keranigonj- 3 (Table- 4.1). The mean EC values ranged from 743 µS/cm at Tejgaon to 5000 µS/cm at Hazaribagh tannery area and the SD ranged from ± 60.80 at Tejgaon to ± 2705.99 at Keranigonj (Appen.Table- 1). The highest EC value was recorded at Keranigonj- 3 near battery industry followed by Hazaribagh tannery- 2 and Hazaribagh tannery- 1 and the lowest was found at Keranigonj- 4 near M.V. Corrugation. EC is associated with soluble salts, dissolved cations and anions. Effluents of battery industry at Keranigonj- 3 contained the highest quantities of different heavy metals and substantially higher amounts of sulphates (Table- 4.1 and 4.2), which might be responsible to enhance the EC at that spot. And, the highest mean EC was observed at Hazaribagh tannery area, which might be due to the use of huge amounts of sodium chloride and other salts in preserving and tanning of hides and skins in tannery industry. The results were in agreement with the findings of Islam *et al*. (2002). Das *et al*. (2010) found higher EC in tannery effluents. Similarly, Thangavel *et al*. (2003) reported that tannery effluents contributed higher electrical conductivity as they were rich in salts, particularly, sodium chloride. Working with tannery effluents of Hazaribagh, Karim *et al*. (2013) found high electrical conductivity (~15,000 µS/cm) as well, because of the presence of cations like Na^+, K^+, Ca^{2+}, Mg^{2+} and anions like sulphate and chloride. Likewise, Venkatesh *et al*. (2009) also found much higher EC values of tannery effluents than the tolerable limit for industrial effluents discharged into land surface and water bodies. On the other hand, at Matuail- 2 near dyeing industry, EC was found slightly higher than permissible limit of DoE (permissible limit is 2000 µS/cm for drinking water), which might be influenced by the effluents discharged from the textile and dyeing industries. Momtaz *et al*. (2012) found a wide range of EC (2060 µS/cm - 12470 µS/cm) of textile effluents due to the release of large amounts of ionic substances like sodium, chloride etc. from textile industries. In other spots of the surveyed areas, EC was found within the permissible limit.

Andrew *et al*. (1972) and APHA (1976) stated that the EC values were influenced by municipal waste and industrial effluents. On the other hand, Ullah *et al*. (1995) and Islam *et al*. (2002) found very high EC values in and around Dhaka. Rande (2000) reported that the discharge of huge quantity of electrolytes from different industries contributes higher EC in wastewaters. Zahid *et al*. (2006) and TICI (2005) were also agreed with these findings.

4.1.1.3 *Conductivity*

Conductivity of an electrolyte solution is a measure of its ability to conduct electricity. Conductivity measurement is used routinely in many industrial and environmental applications, which is inexpensive and reliable way of measuring the ionic content in a solution (Gray, 2004). In many cases, conductivity is directly linked to the total dissolved solids (Web. 4).

Conductivity of wastewaters varied among the sampling sites of the industrial areas in and around Dhaka (Table- 4.1). The conductivity of the collected wastewaters ranged from 342

µS/cm at Keranigonj- 4 near M.V.Corrugation to 5910 µS/cm at Keranigonj- 3 near battery industry (Table- 4.1). The mean conductivity ranged from 840 at Tejgaon to 5656.50 µS/cm at Hazaribagh tannery area and the SD ranged from ±59.10 at Tejgaon to ±2731.72 at Keranigonj (Appen.Table - 1).

At Keranigonj-3, industrial effluents of lead-storage battery contained the highest amounts of Pb, Zn, Ni, Cu ions and substantially high amounts of sulphates (Table- 4.1 and 4. 2), which might be responsible to increase the EC in the wastewater at that spot. The conductivity at Hazaribagh- 1 and 2 near tannery industry and Matuail- 2 near dyeing industry were also found higher than the permissible limit of CPCB and WHO (2100 µS/cm for drinking water). It might be due to the fact that in tannery industries at Hazaribagh, different kinds of salts were used in preserving and tanning of hides and skins, which might be responsible to enhance the density of soluble salts in the nearby water bodies and ultimately escalated the conductivity in the wastewaters at that area. On the other hand, the EC in the wastewaters at Matuail- 2 near dyeing industry was influenced by the effluents discharged from the textile and dyeing industries. It might be owing to the release of large amounts of ionic substances like sodium, chloride, calcium, magnesium etc. from textile industries. Momtaz *et al*. (2012) found high EC in the wastewaters of textile dyeing industries. It should mention here that wastewaters at Matuail- 2 near dyeing industries also contained slightly higher metal ion (Table- 4.2) than other areas, which might be another reason to escalate the conductivty at that location.

According to APHA (1995), conductivity of water is affected by the presence of inorganic dissolve solids such as chloride, nitrate, sulphate and phosphate anions and/or Na, K, Ca, Fe, Al etc. cations. In other spots of the studied areas, conductivity was found more or less within the safe limit. A highly significant positive correlation was found between EC and conductivity (Appen.Table- 38).

4.1.1.4 *Turbidity*

Turbidity is an expression of optical property (Tyndall effect) in which the light is scattered by suspended particles present in water. Scattering of light is dependent upon the size, shape and refractive index of such particles (Gupta, 2001; APHA, 2005).

The turbidity of the wastewaters collected from different industrially polluted areas in and around Dhaka ranged from 5.0 NTU to 616.0 NTU (Table- 4.1). The mean values ranged from 5.56 FTU at Tejgaon to 373.50 FTU at Hazaribagh tannery area, while the SD values varied from ±0.58 at Tejgaon to ±342.95 at Hazaribagh tannery area (Appen.Table - 1).

The highest turbidity value was found at Hazaribagh tannery- 2 near tannery industry followed by Hotapara-1 near Givensse groups, where textile dyeing industries were the main industrial plants from which effluents were discharged to the sampling sites and the lowest was found at Tejgaon-1 inside industrial area. The highest mean value was found at

Hazaribagh followed by Hotapara and the lowest was found at Tejgaon. On the other hand, except Tejgaon industrial area, the turbidity of most of the surveyed areas was found above the acceptable limit of ISI and DoE (10 NTU). In tanning and preserving the skins and hides, chlorides and carbonates of Na, K, Ca and Mg and color pigments were used in tannery industries at Hazaribagh, which might be responsible to enhance the turbidity at that area. The results were in accordance with Chakrapani (2005). Moreover, in dyeing and textile industries, huge amounts of alkalis and color pigments were being used which might also be responsible to increase the turbidity of the wastewater at Hotapara industrial area, where textile dyeing industrial plants were the prime industries. In addition, a lot of suspended particles and color pigments were also observed in the wastewaters at all the sites in and around Dhaka, but at Hazaribagh and Hotapara, suspended particles and color pigments were found exceptionally high. As a matter of fact, a large number of tannery and textile dyeing industries were situated at Hazaribagh and Hotapara industrial areas. It was also surprisingly observed that the textile and dyeing industries were situated at all the industrial clusters in and around Dhaka. So, the turbidity in the wastewaters at other locations of the surveyed areas was found higer than the acceptable limit as described by ISI.

The results corroborate with the findings of several researchers (AEPA, 1998 and Wynne *et al*., 2001). According to AEPA (1998) and Wynne *et al*. (2001), dyes contribute to high level of BOD, salinity, color, toxicity, surfactants, fibers and turbidity and may contain heavy metals. According to USEPA (1991), turbidity caused by soil erosion, waste discharge, urban runoff, excessive algal growth, large number of bottom feeders etc., which stir up bottom sediments. APHA (2005) noted that the turbidity is caused by the suspended particles including soil particles (sand, silt and clay), algae, plankton, microbes and other substances.

4.1.1.5 *Total Dissolved Solids (TDS)*

Total dissolved solid is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular (colloidal soil) suspended form. The principal application of TDS is the study of water quality for streams, rivers and lakes, although it is not generally considered a primary pollutant.

The total dissolved solids in the wastewaters of the studied areas varied from 79 mg/L at Ashulia- 4 near Turag River to 4139 mg/L at Keranigonj- 3 near battery industry (Table- 4.1). The mean values ranged from 601mg/L at Tejgaon to 3964 mg/L at Hazaribagh tannery area and the SD ranged from ±35.68 at Tejgaon to ±1904.16 at Keranigonj (Appen.Table- 1). The elevated and substantially higher values of TDS were found at Hazaribagh tannery- 1 (3929 mg/L), Hazaribagh tannery- 2 (3999 mg/L) and Matuail- 2 (1750 mg/L) (Table- 4.1). The mean TDS of Hazaribagh and Keranigonj was found above the permissible limit and the TDS values at the other locations were found within the permissible limit (< 1000 mg/L) of WHO and DoE. The high TDS values in the wastewaters at Hazaribagh tannery area might be high due to the use of huge amounts of NaCl and other salts, alkalis, color pigments containing

heavy metals and other substances in preserving and tanning of hides and skins in tannery industry. It was also found that the wastewaters at Hazaribagh tannery area contained substantially higher amounts of Na, K, Ca, Mg, Cl^-, NO_2^- -N, NO_3^- -N and NH_4^+ -N, PO_4^{3-} 'SO_4^{2-} and some metal ions (Table- 4.1 and 4.2), which might also be responsible to enhance the TDS at Hazaribagh tannery area. And at the same time, ammonia, nitrate, nitrite, phosphate, alkalis, sulphates and metallic ion concentration at those locations of Hazaribagh area were found higher than other sampling sites (Table- 4.1and 4.2), which might be another reason to escalate the TDS values at those locations. Islam *et al*. (2002) found high TDS in the wastewaters at Hazaribagh area. On the other hand, at Keranigonj -3, the samples were collected from near lead-storage battery industry, where metal ions like Pb, Zn, Ni, Cu and sulphate concentrations were found substantially higher than other areas (Table- 4.1 and 4.2), which might be associated with the increase in the TDS value at that sampling site. In fact, the total dissolved solid (TDS) is a parameter, which gives us the index of dissolved compounds, both organic as well as inorganic present in the wastewaters (APHA, 1998). On the other hand, the TDS values in the textile dyeing industrial wastewaters at different locations of the study areas were also found high. The results were in agreement with the finding of Weiner (2000).

Moore *et al*. (1960) reported that the total dissolved solids (TDS) in water consist mainly of ammonia, nitrate, nitrite, phosphate, alkalis, some acids, sulphates and metallic ions. Ahmed *et al*. (2011) measured higher TDS value in tannery effluents than the textile. However, Gupta *et al*. (2010) reported that EC and TDS are proportional to each other. A positive co-rrelation was found among TDS, EC and conductivity (Appen.Table- 38).

4.1.1.6 *Dissolved Oxygen (DO)*

Oxygen is essential in all forms of life including organisms responsible for the self purification processes in natural waters (UNESCO/WHO/UNEP, 1992). Dissolved oxygen (DO) is an index of physical and biological processes going on in water and non-polluted surface water is normally saturated with dissolved oxygen (Gupta, 2001). Without free dissolved oxygen (DO), the river, streams and lake become uninhabitable to gill breathing aquatic organisms (Vesilind *et al*., 1990).

Dissolved oxygen (DO) of the wastewaters collected from different industrial sites varied within different locations and types of nearby industries. The DO of the collected wastewater samples ranged from 0 (zero) at Hazaribagh tannery- 2 to 4.5 mg/L at Keranigonj- 1near Momtaz Steel Mills Ltd. (Table- 4.1). The mean DO varied from 0.10 mg/L to 3.33 mg/L and the lowest mean value of DO was found at Hazaribagh tannery area and the highest was found at Tejgaon industrial area. And the SD ranged from ±0.06 at Tejgaon to ±1.85 at Keranigonj (Appen.Table- 2).

Dissolved oxygen in most of the wastewaters of the surveyed areas was found much below the permissible limit of DoE (4.5 - 8). But, DO of Hazaribagh tannery- 2 was found zero (Table- 4.1), which suggested that the tannery industries were releasing lot of organic substances most likely the dyes that were high oxygen demanding wastes (Emongor *et al.*, 2005). On the other hand, large amounts of organic substances were generated and released into the nearby water bodies from tannery industries at Hazaribagh tannery area. And during decomposition, microorganisms consumed dissolved oxygen and reduced the DO of the wastewaters. The results were also in agreement with the findings of Islam *et al.* (2002). Likewise, a large amount of untreated industrial organic and solid wastes were also discharged from textile dyeing and different kinds of industries at other sampling sites in and around Dhaka. Then again, the dissolved oxygen (DO) in the wastewaters at different locations varied from place to place (Table- 4.1), because of their variations in the contents of phytoplankton, organic wastes and effluents, colored substances, septic water and untreated domestic sewage (EPA, 1974). In fact, during decomposition and degradation of untreated industrial organic wastes, micro-organisms consumed all or most of the oxygen from wastewaters. Islam *et al.* (2002) observed too low DO in the water bodies, which endangered aquatic lives around Dhaka. The results were also in agreement with the findings of Chapman (1992). He reported that a higher amount of waste discharged in the form of organic matter and nutrients might lead to decrease in DO, which was due to the result of the increased microbial activity (respiration) occurring during the degradation of the organic matter.

Several researchers (Vijayan *et al.*, 1976; Nair and Ganapati, 1983) also reported that DO was considerably influenced by wastewater disposal and sewage discharge. Similarly, Weiner (2000) stated that the dissolved oxygen is consumed by the degradation (oxidation) of organic matter in water. Because the concentration of dissolved oxygen is never very large, oxygen- depleting process can rapidly reduce it to near zero in the absence of efficient aeration mechanisms (Weiner, 2000). In addition, Dewan (1973) and Sharma (1982) found the lower concentrations of DO in summer months and higher in winter months.

Oxygen-demanding wastes are usually biodegradable organic substances contained in municipal wastewaters or in effluents from certain industries, such as food processing and paper production reduces DO of wastewaters (Maters, 1995). Chakraborty *et al.* (1959) suggested the lower DO concentrations during monsoon months presumably associated with the warming up of water, death and decay of planktonic and other organic matter and retarded photosynthetic activity due to reduction in the sunlight caused by cloudy weather condition. Momtaz *et al.* (2012) concluded that the reduction of dissolved oxygen (DO) in the wastewaters was due to the discharges of high oxygen demanding materials from the nearby industry. A negative correlation was found between DO and turbidity (Appen.Table- 38).

4.1.1.7 *Nitrogen*

4.1.1.7.1 Nitrite –N

In the reduction and oxidation processes, nitrite -N is the intermediate stage of nitrogen. High nitrite concentrations are generally indicative of industrial effluents that are often associated with unsatisfactory microbiological population in water (Chapman, 1992).

Nitrite concentration in the wastewaters at different sampling sites ranged from 0 (zero) µg/L at Keranigonj-3 near battery industry to 1950 µg/L at Hazaribagh- 2 near tannery industry (Table- 4.1). The mean nitrite -N ranged from 35.33 µg/L at Tejgaon industrial area to 1905 µg/L at Hazaribagh and the SD ranged from ±20.50 at Savar to ±827.65 at Matuail (Appen. Table- 2).

 Nitrite -N at Hazaribagh tannery- 1, Matuail- 2 near dyeing industry, Gazipur- 2 near Apex tannery and Ashulia- 4 near Aman Spinning Mills Ltd. was also found high, where most of the industrial plants were tannery and textile dyeing. At other sites near textile dyeing industries, nitrite- N was found slightly higher than permissible limit. The highest mean concentration of nitrite -N was found at Hazaribagh followed by Matuail and the lowest was found at Tejgaon (Appen.Table- 2). On the other hand, the mean values of nitrite -N at Matuail, Gazipur and Ashulia was found higher than the permissible limit of DoE (0.2 mg/l), but at other locations of the surveyed areas it was found within the tolerable limit.

The highest nitrite -N was found at Hazaribagh- 2 followed by Hazaribagh- 1 near tannery industry and Matuail- 2 near dyeing industry and almost zero was found at Keranigonj- 3 near battery industries. At the same time, the mean nitrite -N concentration at Hazaribagh tannery area was also found the highest. The results were in agreement with Ahmed *et al*. (2011). They reported that tannery effluents contained higher load of NO_2^- -N than textile effluent. Islam *et al*. (2002) also found higher amounts of nitrite -N at Hazaribagh tannery area. In contrast, Khopkar (2008) reported that textile effluents were rich in organic substances, which might contribute higher nitrite -N near textile dyeing industry. The mean nitrite -N at Gazipur, Matuail and Ashulia was also found high, because a lot of textile dyeing and spinning mills were situated at those sampling sites. The results of the study areas revealed that the nitrite -N concentrations in the wastewaters at different sites of the studied areas were found above the permissible limit (0.2 mg/L) of DoE. In fact, the wastewaters of the surveyed areas were derived mainly from textiles, dyeing and tannery industries etc. that contained extensive amounts of organic substances, which increased the nitrite -N at those locations. Conversely, nitrite -N at Keranigonj- 3 was found zero, because the effluents of battery industries did not contain any organic substances. Ullah *et al*. (1995) obtained extremely hazardous levels of nitrite -N in the effluents discharged into the canals and rivers in and around Dhaka city, which was influenced by industrial activities, urban waste disposal and sanitary landfills. Verlenceur (1987) observed that the industrial effluents and urban wastes were positively correlated with the nitrite concentration of Goa estuary.

Nair and Ganapati (1993) reported that the higher value of nitrite -N content in the river Kallada was influenced by the land discharge and industrial waste disposal. According to APHA (1976), urea manufacturing plant is an important source of nitrite -N in the adjacent water bodies. Ammonia and other nitrogenous materials in natural waters tend to be oxidized by aerobic bacteria, first to nitrite and then to nitrate. All organic compounds containing nitrogen should be considered as potential nitrate and nitrite sources. Higher concentration of nitrite -N was present in industrial wastes, sewage and in biologically purified effluents and in polluted streams (APHA, 2005). Reports from the above authors support the result of present investigation. Nitrites and nitrates are very soluble, do not adsorb readily to mineral and soil surfaces, and are very mobile in the environment (Weiner, 2000).

4.1.1.7.2 *Nitrate –N*

The most common contaminant identified in ground water is dissolved nitrogen in the form of nitrate (NO_3^-). This contaminant is becoming increasingly widespread because of agricultural activities and disposal of sewage on or beneath the land surface (Freeze and Cherry, 1979).

The nitrate -N concentrations of the sampling sites ranged from 0.9 mg/L at Ashulia- 4 near Turag River to 308 mg/L at Demra- 3 near I I Tubes Mills Ltd. (Table- 4.1). And, the mean nitrate -N concentration varied from 4.33 mg/L at Tejgaon to 137.50 at Hazaribagh and the SD ranged from ±2.08 at Tejgaon to ±173.79 at Demra (Appen.Table - 2). The highest concentration was found at Demra- 3 near I I Tubes Mills Ltd. In I I Tubes Mills Ltd., GI, SS and MS tubes and pipes were manufactured by galvanizing and electroplating processes. And, in electroplating process, $Zn (NO_3)_2$ salts were used as electrolyte in salt bridge. On the other hand, to manufacture GI pipes, before galvanization by Zn on iron tubes and pipes, they immerse and wash the iron tubes by concentrated HNO_3 acid to clean the dusts and rusts of the tubes. It might be another source of nitrate -N in the wastewaters near I I Tubes Mills Ltd. High nitrate -N was also found at Hazaribagh- 2 and Hazaribagh- 1 tannery area. Among the sampling sites, the substantially higher nitrate -N was found near tannery and textile dyeing industrial plants except Demra-3. The mean nitrate -N in the wastewaters at Hazaribagh and Savar was also found high, because the samples were collected from adjacent areas of tannery industries at Hazaribagh and textile dyeing industries at Savar. The results were in agreement with Islam *et al*. (2002). They observed substantially high nitrate -N at Hazaribagh tannery area. In contrast, Ahmed *et al*. (2011) found higher NO_3^- -N in textile effluent than the tannery effluent. Similarly, nitrate -N concentration in the wastewater at some other locations near textile dyeing industries of the sampling sites was also found above the tolerable limit of DoE (10 mg/L). But, the mean nitrate -N at Hotapara, Savar and Matuail was also found high. As a matter of fact, untreated industrial organic solid wastes from tannery, textile and dyeing and food and beverage industries were being discharged into the natural water bodies in and around Dhaka randomly. At the same time, versatile types of industries were situated in the vicinity and they discharged their wastes in the same ditch.

According to Ullah *et al*. (1995), randomly discharged industrial waste and effluents increased the nitrate and nitrite content in the water bodies in and around Dhaka. Shamsad *et al*. (1999) also reported that the higher concentration of NO_3^- in the surface water may be due to the discharge of untreated industrial, domestic and municipal wastes. On the other hand, Islam *et al*. (2002) revealed that the tannery residues were rich in protein, which increased the nitrate, nitrite and ammonium contents at Hazaribagh tannery area in Dhaka City. According to APHA (2005), significant sources of nitrate are chemical fertilizers, decayed vegetables and animal matter, domestic effluents, sewage sludge disposal to land, industrial discharge, leachates from refuge dumps and atmospheric wash out.

4.1.1.7.3 *Ammonium -N*

Ammonium is naturally present in surface water, ground water and domestic sewage. It is produced largely by the deamination of organic -N containing compounds and hydrolysis of urea. In water bodies, it is produced naturally by the reduction of nitrates under anaerobic condition (De, 2000).

The ammonium -N concentrations in the wastewaters collected from different industrially polluted areas in and around Dhaka varied from 0.5 mg/L to 230 mg/L (Table- 4.1). The highest concentration was found at Hazaribagh tannery- 2 followed by Hazaribagh tannery- 1 and the lowest was found at Ashulia- 4 near Turag River. And, the mean values ranged from 1.75 mg/L to 217.50 mg/L and the highest was found at Hazaribagh and the lowest was found at Keranigonj (Appen.Table- 2). The SD of ammonium -N varied from ±1.53 to ±23.97 and the highest was found at Demra and the lowest was found at Tejgaon (Appen.Table- 2). Tannery industries at Hazaribagh discharge large amounts of organic wastes and under anaerobic decomposition they produce substantially high ammonium -N. For that reason, the DO in the wastewater at Hazaribagh area was found almost zero (Table- 4.1). But, at different locations near tannery and textile dyeing industries, ammonium- N was found high, which might be due to the discharge of organic wastes from those kinds of industries. Islam *et al*. (2002) and Zahid *et al*. (2006) identified high ammonium in the wastewater at Hazaribagh tannery area as well. On the other hand, ammonia -N at Demra- 3 near I I tubes was found high, because HNO_3 acid and $Zn (NO_3)_2$ salts were derived from electroplating and galvanizing process in the wastewaters of that industry, and under anaerobic condition which might produce high ammonium. Likewise, De (2000) reported that ammonium produced naturally by the reduction of nitrates under anaerobic conditions.

At all spots of the surveyed areas, ammonium -N was found high and above the permissible limit of DoE (0.5 mg/L), which might be due to the discharge of untreated industrial wastes and effluents in the wastewaters near the industrial plants in and around Dhaka. On the other hand, the wastewater ditches of textile and dyeing, food and beverage and metal industries and also municipal wastewater pipes were connected together through drains and canals in almost all the sampling sites. For that reason, all the ditches from which wastewater samples were collected was found rich in organic substances. And, at the same time, a strong reducing

condition also prevailed in all the spots except in few cases, which might also be responsible to escalate ammonium -N in the wastewater of most of the sampling sites. Islam *et al.* (2002) found substantially high ammonium -N in the wastewaters in and around Dhaka. Likewise, Shamsad *et al.* (1998) also reported higher concentration of NH_4^+-N in the surface and ground water which might be due to the discharge of untreated industrial, domestic and municipal water. A positive co-rrelation was found among NO_2^- -N, NO_3^- -N and NH_4^+ -N (Appen.Table- 38).

4.1.1.8 *Sulphates*

Sulphate occurs in wastewaters in both organic and inorganic forms and sources. It is found in natural waters in concentration ranging from a few to several thousand milligrams per liter (De, 2000). Oxidation of sulfur bearing organic materials can contribute sulphate to water (Weiner, 2000; Gupta, 2001).

Sulphate concentration in the wastewaters of the studied areas ranged from 3 mg/L at Demra-3 near I I Tubes Mills Ltd. to 7599.0 mg/L at Keranigonj- 3 near lead-storage battery industry (Table- 4.1). The mean values ranged from 38.67 mg/L to 1954.20 mg/L and the SD ranged from ±6.43 at Tejgaon to ±3763.59 at Keranigonj. The highest mean value was recorded at Keranigonj and the lowest was found at Tejgaon (Appen.Table- 2). At Keranigonj- 3 near battery industry, sulphate concentration was found the highest because of the presence of lead- storage battery industries, where H_2SO_4 acid was used as a medium to dip the anodes and cathodes into aqueous solution or as electrolytes. Except Keranigonj- 3, sulphate concentrations at all other locations of Keranigonj area were found remarkably low. On the other hand, sulphate concentration at Hazaribagh tannery- 1 and Hazaribagh tannery- 2 was found high. And the mean sulphate concentration in the wastewaters at Hazaribagh tannery area was also found higher than other areas, because tannery effluents contained substantial amounts of sulphate as reported by several researchers (Ullah *et al.*, 1995; Nuruzzaman *et al.*, 1998; Ram and Rager, 2004; Ahmed *et al.*, 2011) as well. The reason might be due to the fact that H_2SO_4 acid and sodium sulphate salts were used in tanning and pickling of skins and hides in tannery industries. Then again, sulphate concentration at Savar- 1 near textile dyeing industry was found high. And the mean sulphate concentration at Savar and Hotapara was also found slightly higher than permissible limit, which was associated with the presence of textile dyeing and spinning industries at those locations. The results were in accordance with Hasan and Miah (2014). They found high sulphate in textile dyeing industrial wastewaters. Due to the use of Na_2SO_4, $Na_2S_2O_3$ and Na_2S salts with various dyes in dyeing processes at that textile dyeing industry, sulphate concentration near textile dyeing industries might be high. In other surveyed areas, sulphate concentration was found much below the permissible limit of CPCB and DoE (400 mg/L).

Weiner (2000) revealed that industrial discharge such as tanneries, sulphate-pulp mills, textile plants, sulfuric acid producing factories, metal working industries, and mine drainage wastes

are all sources of sulphate that pollutes water. Air emission from industrial fuel combustion and the roasting of sulfur containing ores carry large amounts of sulfur dioxide and sulfur trioxide into the atmosphere and add sulphates to surface water through precipitation. Besides, sodium sulphate is used in the liming process of hide and skins, which might be the sources of sulphate in the wastewaters near tannery industries (Ram and Rager, 2004). The residual sulphate in the range of 100 - 200 mg/L goes into the discharge and cause serious environmental problem.

4.1.1.9 *Carbonates and bicarbonates and total alkalinity*

Alkalinity is a measure of the buffering capacity of stream water, i.e., the ability of water to resist changes in pH. Stream water with relative high alkalinities has a greater ability to neutralize acidic pollution from rainfall or wastewater, and is able to resist major shifts in pH. Water with low alkalinity is very susceptible to changes in pH. Alkalinity not only helps regulate the pH of a water body, but also the metal content. Bicarbonate and carbonate ions in water can remove toxic metals such as Pb and Cd by precipitating the metals out of solution.

Generally the water shows alkalinity due to the presence of carbonates and bi-carbonates. Both carbonates and bi-carbonates are of importance because of their tendency to combine with and precipitate the divalent cations like Ca^{2+} and Mg^{2+} (Basher *et al.*, 2005). Alkalinity is often taken as an indicator for the concentration of bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and hydroxyl (OH^-) anions. There are other minor contributors to alkalinity, such as ammonia, phosphates, borates, silicates and other basic substances (Weiner, 2000). The dissolved carbonate species, CO_2 (aq) (equivalent to H_2CO_3), HCO_3^-, and CO_3^{2-}, are present in the natural water system near the surface of the earth. The relative proportion depends on pH (Weiner, 2000).

Bicarbonate concentration in the wastewaters of the studied areas ranged from 0 (zero) to 854 mg/L (Table- 4.1). The highest concentration was found at Demra- 2 near Jahir Steel Mills Ltd. followed by Gazipur- 8 near SS Steel Mills Ltd., but it was found almost zero at different locations of the studied areas. In fact, $CaCO_3$ also used in the purification processes of iron ore in a blast furnace of metal industries and different kinds of alkali materials were used in cleaning of metal industries, which might be responsible to increase bicarbonate concentrations near metal industries. On the other hand, bicarbonate concentration at Shampur- 2 near dyeing industry, Demra- 3 near I I Tubes Mills Ltd., Gazipur- 5 near Haq battery and Keraniganj- 3 near battery industry was found zero, where the pH of the wastewaters was strongly acidic and/or extremely alkaline (Table- 4.1).The mean bicarbonate concentration varied from 118.75 mg/L to 538.50 mg/L and the SD ranged from ±21.22 at Tejgaon to ±435.92 at Demra (Appen.Table - 3). The mean concentration at Savar, Hotapara and Hazaribagh near textile dyeing and tannery industries was also found high. As a matter of fact, bi-carbonate concentration in wastewater is directly related to pH. For aquaculture, the

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recommended limit values of bicarbonate (HCO_3^-) concentration in water is from 50 mg/L to 300 mg/L (Body, 1998).

Carbonate concentration in the wastewaters ranged from 0(zero) to 610 mg/L at different locations of the studied areas (Table- 4.1). The highest concentration was observed at Gazipur- 5 near Haq battery. The highest mean carbonate concentration was found at Matuail and the highest SD was found at Gazipur (Appen.Table- 3). Except few locations such at Matuail- 1, Matuail- 2, Tejgaon industrial area- 1, Tejgaon industrial area- 2, Ashulia- 3, Demra- 2, Gazipur- 5, Gazipur- 7 and Savar- 1, Shampur 1, 2 and 3 carbonate contents at all sampling sites were found zero. At the same time, the mean carbonate concentration at Hotapara, Keranigonj and Hazaribagh was also found zero. Carbonate concentration in wastewater is also directly related to pH. Below pH 8.2, no carbonate concentration was found. The result was also in accordance with Weiner (2000). He revealed that pH below 6.3, dissolved CO_2 is the dominant species, between pH 6.3 and 10.3, HCO_3^- is the dominant species and above pH 10.3, CO_3^{2-} is the dominant species. Weiner (2000) stated that it was not unusual for alkalinity to range from 0 to 750 mg/L as $CaCO_3$ in the wastewaters.

According to Balakrishnan and Karruppusamy (2005), carbonate and bicarbonate contribute to the total alkalinity of water. The total alkalinity of wastewater samples ranged from 0(zero) to 1268.10 mg/L (Table- 4.1). The highest total alkalinity was found at Demra- 2, but it was found almost zero at Demra- 3 and Keranigonj- 3. Markedly high total alkalinity was found at Gazipur-5 near Haq battery, Gazipur- 7 at Meghna Ghat Tongi and Matuail- 2 near dyeing industry. The mean total alkalinity of Matuail, Gazipur, Savar and Demra was found above the permissible limit (Appen.Table- 3). Moreover, at different locations of the surveyed areas, the total alkalinity near metal, battery and textile industries was found above the tolerable limit of DoE (>400 mg/L) and CPCB (600 mg/L). Random discharges of wastes and effluents from textile, dyeing, tannery, battery and metal etc. industries together with municipal and domestic wastes and effluents contributed alkalinity in the wastewaters at different locations in and around Dhaka. Mahmood and Bhouyan (1998) found higher values of total alkalinity in the municipal disposed area of river Karnafully. Likewise, Rashid (1996) reported high alkalinity in the Buriganga, the Turag and the Balu River, which were influenced by different industries, domestic wastes of cities and heavy river transport system. Seth and Bhakaran (1950) found higher values of total alkalinity in the industrial waste disposal area of Hoogly River (India) than unpolluted river.

A minimum alkalinity of 20 mg/L as $CaCO_3$ is recommended for environmental waters and levels between 25 and 400 mg/L are generally beneficial for aquatic life and naturally occurring levels of alkalinity reaching at least 400 mg/L as $CaCO_3$ are not considered a health hazard (Weiner, 2000). A positive correlation was found among pH, HCO_3^-, CO_3^{2-} and total alkalinity (Appen.Table- 38).

4.1.1.10 *Phosphate*

Domestic and industrial effluents and agricultural runoff are the major sources of phosphorous in water, and its high concentration is the indicative of pollution (Gupta, 2001). The possible reason behind the high phosphate in water is mixing the discharge of industrial effluents and the waste water from city and towns in water bodies (Hasan and Miah, 2014).

The phosphate concentrations in the wastewaters of the studied areas ranged from 1 mg/L to 95 mg/L (Table- 4.1). The mean concentration ranged from 11.76 mg/L to 69.50 mg/L and the SD ranged from ±1.41 at savar to ±47.08 at Matuail (Appen.Table - 3).

The highest phosphate concentration was found at Matuail- 2 near dyeing industry followed by Hazaribagh tannery- 2 and the lowest was found at Keranigonj- 3 near battery industry. The highest mean concentration was found at Hazaribagh tannery and the lowest was found at Ashulia. Among the sampling sites, phosphate concentrations in the wastewaters near tannery and textile and dyeing industries were found higher than other industrial plants. It might be associated with the use of phosphatic substances in tannery and textile dye. The results were in accordance with the findings of Ahmed *et al*. (2011). They found high phosphate in the tannery and textile industrial wastewaters, which might be due to the use of phosphate containing substances in tannery and textile dyeing industries. The mean phosphate concentrations at Hazaribagh tannery, Matuail and Gazipur were found higher than other sites, where tannery and textile dyeing industries were the prime industrial plants. Phosphate concentrations in most of the wastewaters of the studied areas were found above the tolerable limit (6 mg/L) as described by WHO and DoE. The possible reason behind the high phosphate in wastewater is mixing the discharge of industrial effluents and the wastewater from city and towns as stated by Hasan and Miah (2014).

Several researchers (Chapman, 1992; UNESCO/WHO/UNEP, 1992; Weiner, 2000) stated that domestic and municipal waste water, particularly those containing detergents, industrial effluents, fertilizers and runoff contribute to elevated level of phosphorus in surface water. They also added that phosphorus associated with organic and mineral constituents of sediments in water bodies can also be mobilized by bacteria and release into water column. Similarly, some authors (Sharma *et al.,* 1982; Balakrishnan and Aziz, 1984; Verlenceur, 1987) also reported that organic pollution caused by the discharge of domestic sewage and industrial waste increased phosphate concentrations in the respective water bodies. De (2000) stated that phosphate occurred in natural and wastewaters as inorganic and organically bound phosphate. Phosphates are largely used for laundry purposes, treatment of boiler's waters and agriculture. Organic phosphates are formed primarily by biological processes, but are also contributed by domestic sewage.

4.1.1.11 *Chloride*

Most chlorine occurs as chloride in solution. It enters into the surface water with the atmospheric deposition of oceanic aerosols, with the weathering of some sedimentary rocks, industrial and sewage effluents, agricultural and road run off (UNESCO/WHO/UNEP, 1992). As chloride is frequently associated with sewage, it is often incorporated into assessment as an indication of possible faecal contamination or as a measure of the extent of the dispersion of sewage discharges in water bodies.

Chloride concentration in the wastewaters of the sampling sites varied from 20 mg/L to 5501 mg/L (Table- 4.1). The mean chloride concentration ranged from 103.25 mg/L at Keranigonj to 4505 mg/L at Hazaribagh and the SD ranged from ±23.35 at Shampur to ±1408.55 at Hazaribagh tannery area (Appen.Table- 3). The highest chloride concentration was found at Hazaribagh tannery- 2 followed by Hazaribagh tannery- 1 and the lowest was found at Keranigonj- 3 near battery industry (Table- 4.1). The highest mean chloride concentration was also found at Hazaribagh tannery area and the lowest was found at Keranigonj. It was probably due to the use of various chloride containing salts in pickling and initial preservation processes of leather. The results were in agreement with several scientists (Nuruzzaman *et al*., 1998; TICI, 2005; Zahid *et al*., 2006; Karim *et al*., 2013). They found extremely high chloride concentration in the wastewater of Hazaribagh tannery area. Similarly, Islam *et al*. (2002) also reported high concentration of chloride in the wastewater in and around Dhaka. On the other hand, chloride concentration in the wastewaters at Matuail- 2 near dyeing industries was found above the DoE (150 - 600 mg/L) drinking water standard. Textile dye may contain chloride containing salts. Ahmed *et al*. (2011) observed high chloride in the wastewaters near textile dyeing industries. On the other hand, the lowest chloride was recorded at Keranigonj- 3 near battery industry, where no salts were used in manufacturing lead-storage battery. It is important to mention that chloride is an indicator of pollution, when present in higher concentration. But, at other locations of the studied areas, chloride concentration was found lower and much below the permissible limit of DoE (150 - 600 mg/L).

Chapman (1992) reported that elevated concentrations of chloride can occur near industrial sewage effluents discharge areas, irrigation drains, salt water intrusion in coastal rivers etc. APHA (1976) and Bhouyan (1979) reported that industrial effluents contained high concentrations of chloride, which might increase the chloride concentration in the water bodies, where the effluents were being discharged.

In fact, chlorides are widely distributed in nature, usually in the form of sodium, potassium and calcium salts (NaCl, $CaCl_2$, KCl) although many minerals contains small amounts of chloride as an impurity. Chlorides in natural water arise from weathering of chloride minerals, salting of roads for snow and ice control, sea water intrusion in the coastal regions, irrigation, drainage, and industrial wastewaters. And, chloride is not sorbed to soils and

moves with water with little or no retardation (Weiner, 2000). Bashar *et al.* (2005) reported that industrial effluents, municipal sewage sludge and salt water intrusion from the Bay of Bengal into the river Karnafuli might be responsible for high concentration of chloride. The presence of very high amounts of chloride and sulphate is responsible for high hardness (Kannan *et al.*, 2005). A positive correlation was found between PO_4^{3-} and Cl^- (Appen.Table-38).

4.1.1.12 Cations and Heavy Metal Concentrations

Due to unplanned industrialization and the diversity of industrial plants, wastewaters in and around Dhaka contain different types of cations and heavy metals in varying amounts. The analytical results of the wastewaters collected from different industrial areas are presented in Table- 4.2 and their mean values and SD are presented in Appen.Table- 4 and 5.

4.1.1.12.1 *Sodium*

The Na contents in the collected wastewater samples ranged from 13 mg/L at Demra- 2 near Jahir Steel Mills Ltd. to 1460 mg/L at Hazaribagh tannery- 2 (Table- 4.2). The mean Na concentration ranged from 21 mg/L at Demra to 1407.50 mg/L at Hazaribagh tannery area and the SD ranged from ±6.18 at Keranigonj to ±74.25 at Hazaribagh tannery area (Appen.Table- 4). Among all the sampling sites, the highest Na concentration was found at Hazaribagh tannery- 2 and the highest mean value was also found at Hazaribagh tannery area. It might be due to the use of substantial amounts of Na salts as a dehydrating and antiseptic agent in tannery industries at Hazaribagh tannery area for preserving skins and hides as described by Mehdi (2005). Similarly, high Na concentration was also observed by Islam *et al.* (2002) at Hazaribagh and other industrial clusters in and around Dhaka. The results were also agreed with the findings of TICI (2005) and Zahid *et al.* (2006). They found extremely high amounts of Na in the wastes and effluents at Hazaribagh tannery. Likewise, Karim *et al.* (2013) reported that tannery effluents contain higher amounts of Na^+.

Sodium concentrations in the wastewaters at Gazipur- 2(210 mg/L) near Appex Tannery, Gazipur- 7(168 mg/L) at Meghna Ghat, Tongi, Matuail-2 (150 mg/L) near dyeing, Savar-1 (103 mg/L) near Doel Group and Ashulia- 3 (95 mg/L) near Aman Spinning Mills Ltd. were found high, where tannery, textile and dyeing industries were the main industrial plants at those sites. It might be due to the fact that textile dyes contain high sodium salts. Reddy *et al.* (2008) found 7900 mg/kg Na^+ in textile dyeing industrial effluents and Hussein (2013) revealed that typical textile wastewater contained 400 - 2175 mg/L Na. Similarly, Hasan and Miah (2014) found high sodium in textile industrial wastewaters. On the other hand, Na concentrations in the wastewaters at all the sampling sites were found above USPHS (1993) drinking water standard (10 mg/L) but within the tolerable limit (200 mg/L)

Table- 4.2: Analytical Results of Some Cations and Heavy Metal Concentrations in the Wastewaters Collected from Different Industrial Areas in and Around Dhaka

No.	Locations	Some Cations (mg/L)				Some Heavy Metals (mg/L)				
		Na	K	Ca	Mg	Zn	Cu	Ni	Pb	Cd
1	**Ashulia-1** (Shariar Fabrics**)**	84.0	12.0	115.0	50.0	0.09	0.027	0.0392	0.015	0.009
2	**Ashulia-2** (Horizon Group**)**	74.0	16.0	100.0	40.0	0.05	0.017	0.0049	0.019	0.010
3	**Ashulia-3**(Aman Spinning Mills Ltd**.)**	95.0	8.0	115.0	304.5	0.095	0.054	0.0104	0.013	0.009
4	**Ashulia- 4 (** Near Turag River**)**	14.0	6.0	40.0	13.0	0.04	0.003	0.0145	0.017	0.008
5	**Demra-1** (Apollo Ispat and CSM Ltd**.)**	30.0	8.0	78.05	11.1	0.07	0.008	0.0148	0.009	0.004
6	**Demra-2** (Jahir Steel and RRM Ltd**.)**	13.0	18.0	120.0	25.0	0.05	0.054	0.0131	0.019	0.006
7	**Demra-3** (I ITubes Mills Ltd.)	20.0	10.0	30.0	15.0	19.25	0.024	0.0206	0.004	0.002
8	**Gazipur-1** (Konabari Industrial Area)	60.0	10.0	100.0	30.0	0.85	0.067	0.1583	0.021	0.007
9	**Gazipur-2**(Apex Tannery, Tongi)	210.0	16.0	90.0	56.0	0.72	0.009	0.0284	0.008	0.005
10	**Gazipur-3** (BISIC, Tongi)	55.0	18.0	60.0	31.0	0.95	0.008	0.0143	0.009	0.006
11	**Gazipur-4**(Metrocem Ispat Ltd**.)**	66.0	16.0	97.0	28.0	0.67	0.008	0.0331	0.016	0.004
12	**Gazipur-5** (Haq Battery, Tongi)	76.0	90.0	25.0	20.0	1.51	0.093	0.3931	0.095	0.009
13	**Gazipur-6** (Mail Bazar, Tongi)	57.0	22.0	80.0	41.0	0.88	0.007	0.0221	0.006	0.008
14	**Gazipur-7** (Meghna Ghat, Tongi)	168.0	18.0	40.0	30.0	0.81	0.031	0.0080	0.023	0.015
15	**Gazipur-8** (S S Steel Mills Ltd.)	54.0	14.0	70.0	30.0	0.95	0.008	0.0154	0.004	0.003
16	**Hazaribag-1** (Hazaribagh Tannery)	1355.0	74.0	140.0	75.0	0.45	0.021	0.0065	0.024	0.019
17	**Hazaribag-2** (Hazaribagh Tannery)	1460.0	80.0	110.0	60.0	0.55	0.043	0.0067	0.031	0.018
18	**Hotapara-1**(Givensee Groups**)**	45.0	34.0	5.7	5.9	0.05	0.013	0.0120	0.006	0.009
19	**Hotapara-2(** Givensee Groups**)**	33.0	21.0	5.1	3.5	0.04	0.009	0.0250	0.009	0.013
20	**Hotapara-3(** Givensee Groups**)**	22.0	29.0	5.9	4.5	0.01	0.011	0.0180	0.007	0.015
21	**Keranigonj-1** (Momtaz S M Ltd.)	29.0	15.0	61.0	19.0	0.05	0.004	0.0036	0.005	0.003
22	**Keranigonj-2** (Dyeing Industry)	41.0	17.0	85.0	13.0	0.03	0.008	0.0091	0.002	0.002
23	**Keraniganj-3** (Storage Battery Ind**.)**	38.0	6.0	5.0	4.1	14.50	5.70	1.9100	6.45	0.001
24	**Keraniganj-4** (M. V. Corrugation)	29.0	10.0	65.0	20.0	0.09	0.009	0.0012	0.011	0.004
25	**Matuail-1** (Asmat Ali S.M.Ltd.)	59.0	13.0	6.22	6.4	0.02	0.003	0.0060	0.019	0.008
26	**Matuail- 2**(Dyeing Industry**)**	150.0	20.8	38.50	20.4	0.24	0.570	0.0040	0.090	0.003
27	**Matuail-3** (Dastagir S.M.Ltd.)	70.9	17.0	37.0	7.70	0.01	0.011	0.0090	0.025	0.003
28	**Savar-1** (Doel Group**)**	103.0	18.0	80.0	45.0	0.07	0.018	0.0146	0.003	0.007
29	**Savar-2** (Ernlima Yarn**)**	45.0	14.0	97.0	6.1	0.06	0.007	0.0031	0.002	0.005
30	**Shampur-1**(Samia S R M Ltd.)	64.3	21.5	8.04	18.6	0.02	0.040	0.0090	0.022	0.002
31	**Shampur-2**(Rupashi Dyeing I Ltd**.)**	20.5	23.0	31.1	7.0	18.50	0.200	0.0080	0.031	0.009
32	**Shampur-3** (Kadamtali S.M.Ltd**.)**	25.3	29.0	23.0	6.70	0.01	0.009	0.0050	0.015	0.005
33	**Tejgaon-1** (Industrial Area)	57.2	14.2	5.48	8.0	0.09	0.006	0.0107	0.014	0.006
34	**Tejgaon-2** (Industrial Area)	35.7	8.0	5.50	8.2	0.06	0.003	0.0450	0.011	0.007
35	**Tejgaon-3** (Industrial Area)	55.0	16.0	7.00	7.9	0.03	0.060	0.0540	0.014	0.009

of DoE and WHO except Hazaribagh tannery-1 and 2. In fact, rain water and other surface and urban runoff washed out salts from different lands, roads and urban areas and then were deposited into the depression and wastewater ditches from which samples were collected. It might be associated with the increase in Na in the wastewaters at other sites of the sampling areas. On the other hand, due to unplanned industrialization, tannery, textile and dyeing, metal and other industrial wastewaters and also municipal wastewaters were mixed together through drains and channels all along the sampling areas, which might also be responsible to enhance Na status at different locations of the surveyed areas.

4.1.1.12.2 *Potassium*

Like sodium, K concentrations in wastewaters at different sites in and around Dhaka varied remarkably. Potassium of the studied areas ranged from 6 mg/L to 90 mg/L (Table- 4.2). The mean K ranged from 10.50 mg/L at Ashulia to 77.0 mg/L at Hazaribagh tannery area and the SD ranged from ±2.83 at Savar to ±26.29 at Gazipur (Appen.Table- 4). The highest amount of K was recorded at Gazipur- 5 near Haq Battery, followed by Hazaribagh tannery- 2 and Hazaribagh tannery-1 and the lowest was found at Ashulia- 4 near the Turag river. In Haq battery, KOH was used as electrolytes for the production of alkaline batteries, which might contribute the highest K at Gazipur- 5.

On the other hand, different kinds of Na and K salts were used in dehydrating and tanning process in tannery industry, which might be responsible to enhance K concentrations in the wastewaters at Hazaribagh tannery area. The results were in agreement with the findings of TICI (2005) and Zahid *et al*. (2006). They found extremely high concentrations of K at Hazaribagh tannery areas. Similar findings were also reported by Karim *et al*. (2013). They revealed that tannery effluent contained higher amounts of K. At other sites of the sampling areas, K concentration was also found much higher than the tolerable limit (DoE standard, 12 mg/L). This is because K salts are randomly used in tannery, food and beverage, electrode plating, textile dyeing, medicine, drilling fluid, mud and chemicals industries and also as NaCl salt substitute. Hussein (2013) reported that typical textile wastewater contained 30- 50 mg/L potassium. On the other hand, in electroplating process, K salts were used in salt bridge. It might be associated with the escalating K concentrations in most of the sampling sites in the wastewaters of the surveyed areas.

It is also important to mention that in every industrial cluster, diversified industrial plants such textile and dyeing, food and beverage, tannery and electroplating etc. are present, which might also be associated with the increase in K in the wastewaters in and around Dhaka. Similarly, Islam *et al*. (2002) found high K concentration in the wastewaters at different locations in and around Dhaka. A positive correlation was found between Na and K (Appen.Table- 38).

4.1.1.12.3 *Calcium*

The Ca contents in the wastewaters of the investigated sites varied remarkably among different locations. Calcium concentration in the wastewaters ranged from 5.0 to 140 mg/L (Table- 4.2). The mean concentration ranged from 5.57 mg/L at Hotapara to 125 mg/L at Hazaribagh tannery area and the SD ranged from ±0.42 at Hotapara to ±45.03 at Demra (Appen.Table- 4). The highest concentration was found at Hazaribagh tannery- 1 followed by Demra- 2 near Jahir Steel Mills Ltd. and Ashulia- 3 near Aman Spinning Mills Ltd., Ashulia- 1 near Shahriar Fabrics and Hazaribagh tannery-2 and the lowest was found at Keranigonj- 3 near lead-storage battery industry. Similarly, Ca concentration was found high at Ashulia- 2 near Horizon Group, Gazipur-1 at Konabari industrial area and other locations near textile dyeing, tannery and metal industries. On the other hand, the highest mean concentration was found at Hazaribagh tannery area and at Ashulia, Demra, Hazaribagh and Savar, the values were found above the tolerable limit of DoE (75 mg/L). It was also observed from the analytical results that higher Ca concentration was found in wastewaters near tannery, textile and dyeing and metal industries. The results were agreed with the findings of several authors (Zahid *et al*., 2006; Ahmed *et al*., 2011; Karim *et al*., 2013). Karim *et al*. (2013) found extremely high concentration of Ca in tannery wastewaters collected from Hazaribagh. The similar findings were also reported by TICI (2005) and Zahid *et al*. (2006). Likewise, Islam *et at*. (2002) observed high Ca in the wastewaters at Hazaribagh tannery area. On the other hand, Ahmed *et al*. (2011) found substantially higher amounts of Ca in textile effluents. It is also important to mention that $CaCO_3$ is also being used in the purification processes of iron ore in a blast furnace in metal industry, which might enhance Ca in the wastewaters near metal industries.

Indiscriminate discharge of untreated industrial wastes and effluents into natural water bodies is a common phenomenon in Bangladesh. And, diversified types of industries are situated in every industrial cluster in and around Dhaka. In fact, the sources of Ca in wastewaters in and around Dhaka are tannery, textile and dyeing, food and beverage, water processing, sewage treatment, paper industry, preparation of dry mixtures for printing and decorating, sugar industry, medicine and food colors.

4.1.1.12.4 *Magnesium*

The Mg concentration in the wastewaters of the studied areas varied greatly among different sites of the sampling areas. The concentrations ranged from 3.50 mg/L to 304.50 mg/L (Table- 4.2). The highest concentration was recorded at Ashulia- 3 near Aman Spinning Mills Ltd. and the lowest was found at Hotapara- 2 near Givensee groups. The mean Mg concentrations ranged from 4.63 mg/L to 108.88 mg/L and the SD ranged from ±0.15 at Tejgaon to ±135.98 at Ashulia (Appen.Table- 4). On the other hand, the highest mean concentration was found at Ashulia and the lowest was found at Hotapara. But, the mean Mg concentration at Hazaribagh tannery area was also found high. Textile dyeing and spinning

mills were the dominant industrial plants at Ashulia and a huge number of tannery industries were situated at Hazaribagh tannery area. However, among the surveyed areas, Mg concentration at different locations near textile dyeing and tannery industry was found high. But, exceedingly high amounts of Mg was found at Ashulia- 3 near Aman Spinning Mills Ltd., which might be due to decolorising activities of textile fabrics and textile effluents by $MgCl_2$, $6H_2O$ salts as coagulants in that industry. The result was in agreement with Verma *et al*. (2012). For bleaching and dyeing, different kinds of chemicals such as defoams, detergents, bleaches and huge amounts of alkalis were used in textile dyeing and spinning industry and those chemicals might contain high Mg. Halimoon and Yin (2010) reported that 2000 types of chemicals and 7000 types of dyes were used in textile dyeing and spinning industries. Mg concentration at Hazaribagh tannery area was found substantially high as well. The result was in accordance with the finding of Islam *et al*. (2002) and Karim *et al*. (2013). Islam *et al*. (2002) found considerable amounts of Mg at Hazaribagh tannery area and other locations in and around Dhaka. As a matter of fact, it is impotent to note that $MgCO_3$ is also used in the purification processes of iron ore in a blast furnace in metal industry, which might be associated with the increase in Mg concentration in the wastewaters near metal industries at different sites of the sampling areas. According to DoE, Mg concentration standard for drinking water is ranged from 30 - 35 mg/L and WHO standard is 150 mg/L. A positive correlation was found between Ca and Mg (Appen.Table- 38).

4. 1.1.12.5 *Zinc*

Zinc in the wastewaters as collected from different industrial areas ranged from 0.01 to 19.25 mg/L (Table- 4.2). The mean concentration ranged from 0.03 mg/L at Hotapara to 6.45 mg/L at Demra and the SD ranged from ±0.01 at Savar to ±11.08 at Demra (Appen.Table- 5). The higher Zn concentration was found at Demra- 3 (19.25 mg/L) near I I Tubes Mills Ltd., followed by Shampur- 2(18.50 mg/L) near rayon dyeing industry and Keranigonj- 3(14.50 mg/L) near battery industry and the lowest was found at Matuail- 3, Shampur- 3 and Hotapara- 3. Except those sites, Zn concentrations at other locations of the studied areas were found within the permissible limit (5 mg/L) of DoE and WHO.

In the wastewaters at Demra- 3 near I I Tubes Mills Ltd., Zn concentration was found high, because rustproof GI, MS and SS sanitary tubes and pipes and rods were manufactured in that industry by galvanizing and electroplating process. And, during galvanization, pieces of iron tubes were immersed in a tank of molten Zn to give Zn coatings on iron tubes to prevent corrosion. On the other hand, during electroplating process in I I Tubes Mills Ltd., Zn salts were also used as electrolyte to give Zn coatings on iron pipes. Hence, Zn metals were used as anode and iron pipes were used as cathode. That is why; Zn concentration in the wastewaters at Demra- 3 near I I Tubes Mills Ltd. might be substantially high. Zn is handled in large quantities at scrapping sites, mainly due to widespread use as anode. On the other hand, De (1996) revealed that Zn entered into the domestic water supply from the deterioration of galvanized Fe and dezincification of brass besides industrial wastes.

Conversely, in manufacturing dry cells and storage batteries, Zn was also used as anode. It might be associated with the increase in Zn concentration at Keranioanj- 3 near battery industry. Then again, at Shampur-2 dyeing industrial wastewaters contained substantially higher amounts of Zn. The result was in agreement with Khopkar (2008). He reported that rayon dyeing wastes and effluents contained high level of Zn. In other sites of the surveyed areas, Zn concentration was found within the permissible limit of DoE and WHO (<5 mg/L). In fact, Islam *et al*. (2002) found high Zn in the wastewaters at different location around Dhaka. Likewise, Hass and Vamos (1995) found Zn in industrial wastewaters. Similarly, Nuruzzaman *et al*. (1998) also observed high Zn in tannery wastewater at Hazaribagh. Ahmed *et al*. (2011) also revealed that tannery effluents mostly comprises of the dissolved substances and inorganic salts of Zn and other cations, and textile dyes contained Zn as impurities.

4.1.1.12.6 *Copper*

Copper in the wastewaters of the surveyed areas ranged from 0.003 to 5.70 mg/L (Table-4.2). The mean concentration ranged from 0.011 mg/L at Hotapara to 1.43 mg/L at Keranigonj and the SD ranged from ±0.002 at Hotapara to ±2.84 at Keranigonj (Appen.Table- 5).

The highest Cu concentration was found at Keranigonj- 3 near lead- storage battery industry and the lowest was found at Ashulia- 4 near the Turag River. Cu concentration at Matuail- 2 and Shampur- 2 near dyeing industries, and Gazipur- 5 near Haq Battery was found slightly high but within the permissible limit as suggested by DoE and WHO (<1 mg/L). But, the highest Cu concentration was found at Keranigonj- 3 near storage battery industry, which was much above the permissible limit. It might be associated with the fact that Cu plates were used in manufacturing storage battery as an anode, which contributed high Cu in the wastewaters at that site. On the other hand, Cu concentration in the wastewaters at Matuail- 2 and Shampur- 2 near dyeing industries was found slightly high, where copper salts might be used with dyeing chemicals in those textile dyeing industries. Halimoon and Yin (2010) reported that Cu was widely used for the production of color pigment of textile dyes. In contrast, Cu concentration in the wastewaters at Shampur-1 near steel and Gazipur- 5 near Haq battery was found slightly high, but below the permissible limit of DoE and WHO. According to Hass and Vamos (1995), the main source of Cu in wastewater are batteries, pigments, printing products, chemicals using copper salts, chemicals using copper catalysts, metal processing products etc. Conversely, Njit (2013) found Cu in the wastewaters from a number of industries producing metal plated products and iron ore crushing plant. Moreover, Islam *et al*. (2002) measured 145, 300, 258 and 210µg/L Cu in the wastewaters at Hazaribagh, Tejgaon, Dholaikhal and Pagla of Dhaka, respectively. Copper concentration in the wastewaters at other sites of the surveyed areas was found within the permissible limit.

4.1.1.12.7 *Nickel*

In the study areas, Ni concentration ranged from 0.0012 to 1.91 mg/L. The highest Ni concentration was found at Keranigonj- 3 near Battery industry and the lowest was found at Keranigonj- 4 near M.V.Corrugation (Table- 4.2). The mean Ni concentration varied from 0.006 to 0.481 mg/L and the SD ranged from ±0.001 at Hazaribagh to ±0.95 at Keranigonj (Appen.Table- 5). The highest mean Ni concentration was found at Keranigonj and the lowest was found at Matuail. Except Keranigonj- 3 and Gazipur- 5 near battery industries, Ni concentrations at other spots were found within the irrigation water standard (0.05 mg/L) of CPCB. At Keranigonj-3, lead- storage batteries were manufactured at those industries, where Ni was also used as cathode. On the other hand, for the production Ni-oxide storage battery, iron was used as anode and Ni plate with Ni_2O_3 dusts were used as cathode. For that reason, Ni concentration in the wastewaters at Keranigonj-3 near battery industry was found the highest. Conversely, Ni based dry cell batteries were manufactured in Haq Battery Ltd. at Gazipur- 5. And, for the production of Ni based rechargeable dry cell batteries, Ni oxides and hydroxides and other metallic cations were used as electrode. It might be responsible to enhance Ni concentration in the wastewaters at Gazipur- 5 near Haq battery. And, the effluents derived from battery industry may contain high Ni that might increase the Ni concentration in the nearby water bodies. The results were in agreement with Chamon *et al*. (2009). They reported that the presence of battery industry increased Ni concentration at different industrial areas.

The mean Ni concentration at Gazipur and Tejgaon areas was found slightly higher than other surveyed areas. The presence of battery industry, metal plating, steel and rerolling, dyeing, textile and spinning mills contributed higher Ni concentrations in the wastewaters at Gazipur area. Similarly, electroplating by nickel is a very usual function at Tejgaon areas. And some battery industries were also present at those sites. The result is in agreement with Chamon *et al*. (2009). They reported that the presence of battery industry increased Ni at Tejgaon industrial area. In addition, Njit (2013) revealed that Ni is found in metal products, steel and chemicals.

4.1.1.12.8 *Lead*

Lead is a relatively immobile element and in alkaline medium, it precipitates as Pb $(OH)_2$ and mobility being retarded.

Lead concentration in the wastewaters of the studied areas ranged from 0.002 to 6.45 mg/L (Table- 4.2). The mean concentrations ranged from 0.003 to 1.62 mg/L and the SD ranged from ±0.0007 at Savar to ±2.45 at Keranigonj (Appen.Table- 5). The highest concentration was found at Keranigonj- 3 near battery and the lowest was found at Keranigonj- 2 and Savar- 2 near dyeing industries. Pb concentration at Gazipur- 5 near Haq battery and Matuail- 2 near dyeing industry was also found above the permissible limit of DoE (0.05 mg/L). On the other hand, the highest mean value of Pb was recorded at Keranigonj and the lowest was

found at Savar. Except Keranigonj- 3 near lead-storage battery, Gazipur- 5 near dry cell battery and Matualil- 2 near textile dyeing industries, Pb concentrations in other sites were found within the DoE drinking water (0.05 mg/L) standard. In manufacturing lead-storage and dry cell batteries, Pb was used as anode, which was associated with the increase in Pb concentration in the wastewaters at Keranigonj- 3 near lead-storage battery industry and Gazipur- 5 near Haq battery. The results were in accordance with the findings of Mondol *et al*. (2011). They revealed that the increased Pb concentrations in wastewaters might be due to the discharge of Pb from the adjoining battery industries. Njit (2013) also reported that battery, pigment and printing products were the main sources of Pb in industrial wastewaters. On the other hand, Halimoon and Yin (2010) and Kant (2012) revealed that Pb was an important constituent of textile dyes, which might be associated with the rise in Pb concentration in the wastewaters at Matuail- 2 near dyeing industry. Conversely, Islam *et al*. (2002) revealed that tannery effluents contain higher amounts of Pb. It could be concluded that due to the unplanned and indiscriminate industrialization by tannery, textile and dyeing, metal and battery might contribute high Pb at different spots of the surveyed areas in and around Dhaka. A positive correlation was found among Zn, Cu, Ni and Pb (Appen.Table-38).

4.1.1.12.9 *Cadmium*

Cd concentration in the wastewaters ranged from 0.001 to 0.019 mg/L (Table- 4.2). The mean concentration ranged from 0.003 to 0.0185 mg/L and the SD ranged from ±0.001 at Savar and Keranigonj to ±0.008 at Ashulia (Appen.Table- 5). The highest concentration was recorded at Hazaribagh tannery- 1 near tannery industry and the lowest was found at Keranigonj- 3 near battery industry. Cd concentrations at Hazaribagh tannery- 2, Hotapara- 2 and Hotapara- 3, Matuail- 3 and Ashulia- 2 near textile dyeing industries were also found high. On the other hand, the highest mean value of Cd was found at Hazaribagh, followed by Hotapara and the lowest was found at Keranigonj.

The highest and the highest mean value of Cd was found at Hazaribagh tannery area. The results corroborated with Imamul Haq (1998) and Shabnam *et al*. (2009). They detected higher amounts of Cd in the tannery effluents at Hazaribagh. On the other hand, higher amount of Cd was found at Hotapara, which might be due to the presence of large numbers of textile dyeing industries at that area. Halimoon and Yin (2010) reported that Cd was widely used for the production of color pigment of textile dye and Kant (2012) also agreed with the same statement. At other sites of the sampling areas, Cd concentration was also found above the permissible limit (< 0.005 mg/L) of DoE. As a matter of fact, industrial clusters in and around Dhaka were not well planned. And, the wastewater ditches of different industries were interconnected by drains and canals. On the other hand, Cd is a mobile element and it can move even 500 km away from the source point (Adriano, 1986). Due to the movement of Cd from different textile dyeing and tannery industries through drains and canals, Cd levels in most of the sampling sites had increased. Conversely, Dhaka is a city, where all kinds of

industries are situated in every industrial cluster. For all these reasons, Cd concentration in the studied areas might be high.

Mondol *et al.* (2011) reported high content of Cd in the water samples, which might be due to the discharge of wastes and effluents from the electroplating industries in the catchments of the canal and also from the surface drain pipe or septic tank pipe connected to the canal of the study area. Likewise, Njit (2013) revealed that Cd might add to industrial wastewaters from electroplated products, pigments, textile and synthetic chemicals. Kant (2012) reported that Cd made the textile effluents highly toxic. No correlation was found among Cd and other metal ions (Appen.Table- 38).

4.1.2 Polluted Soils (Physico-Chemical Properties):

Bangladesh with an increasing industrialization threatens environmental quality and ecosystem, because most of the industries are discharging and dumping their wastes without treatments into the nearby water bodies or in agricultural field. So, the soils in and around Dhaka are being polluted gradually due to unplanned industrialization and random discharge of industrial wastes and effluents. Analytical results of some physico-chemical properties of the collected soil samples are presented in Table- 4.3 and their mean values and SD are presented in Appen.Table- 6 and 7.

4.1.2.1 *Hydrogen-ion concentration (pH)*

pH of the collected soil samples ranged from 2.85 to 10.18 (Table- 4.3). The lowest pH value was found at Keranigonj- 3 (2.85) near Battery industries, followed by Demra- 3 (3.77) near I I Tubes Mills Ltd. and Hotapara- 1 (4.16) near Givensee Groups and the highest was found at Matuail- 2(10.18) near textile dyeing industry. The mean value of pH ranged from 5.28 at Hotapara to 9.20 at Matuail and the SD ranged from ±0.11 at Ashulia to ±1.99 at Keranigonj (Appen.Table- 6). The pH of the soils at Keranigonj- 3 near battery industry was found extremely acidic (2.85). It might be due to the use of concentrated H_2SO_4 acid in the production of lead- acid storage battery as electrolytes in that industry. On the other hand, the pH of the soils at Demra- 3 near I I Tubes Mills Ltd. was also found extremely acidic (3.77). It is important to note that I I Tubes Mills Ltd. is a GI, MS and SS steel and sanitary tubes and pipes manufacturing industry using galvanizing and electroplating processes. And, before galvanization by Zn on iron tubes, they immerse iron pipes in concentrated HNO_3 acid and HCl acid to make the tubes dusts and rusts free, which ultimately enrich the wastewaters with strong acids. It might be associated with the lowering of the pH at Demra- 3. On the other hand, the soils near I I Tubes Mills contained substantial amounts of Zn^{2+} and Fe^{3+} ions and during hydrolysis they might produce huge amounts of H^+ ions and also made the soils acidic. The result was in accordance with the findings of Wuana and Okieimen (2011).

Table- 4.3: Analytical Results of Some Physico-chemical Properties of Soils Collected from Different Industrial Areas in and Around Dhaka

No.	Location	pH	EC (μS/cm)	OC (%)	TN (%)	TP (%)	Na (%)	K (%)	Ca (%)	Mg (%)
1	**Ashulia-1**(Shariar Fabrics**)**	6.74	292	1.88	0.24	0.19	0.32	0.17	1.45	0.29
2	**Ashulia-2**(Horizon Groups**)**	6.95	115	2.33	0.31	0.23	0.32	0.14	1.65	0.15
3	**Ashulia-3** (Aman Spinning**)**	6.79	444	1.99	0.25	0.18	0.65	0.19	1.23	0.75
4	**Demra- 1**(Appolo I & C S M Ltd**.)**	7.92	563	0.70	0.11	0.07	0.41	0.11	1.45	0.83
5	**Demra-2** (Jahir Steel M Ltd.)	7.15	561	1.47	0.20	0.15	0.52	0.21	1.76	0.23
6	**Demra-3** (I I Tubes Mills Ltd.)	3.77	141	1.50	0.25	0.15	0.34	0.12	1.57	0.12
7	**Demra-4**(Alaksa Steel M Ltd**.)**	6.51	320	1.80	0.23	0.18	0.75	0.90	1.60	1.03
8	**Gazipur-1**(Konabari I Area**)**	6.26	514	1.90	0.24	0.18	0.82	0.40	1.09	0.44
9	**Gazipur-2** (Appex Tannery, Tongi**)**	7.50	599	2.10	0.27	0.21	0.19	0.90	1.20	0.50
10	**Gazipur-3** (BISIC, Tongi**)**	7.98	1232	1.25	0.16	0.13	0.77	0.71	2.62	0.18
11	**Gazipur-4** (Metrocem Ispat Ltd.)	8.16	890	0.29	0.04	0.03	0.66	0.28	0.97	0.82
12	**Gazipur-5** (Haq Battery, Tongi**)**	6.59	750	1.50	0.21	0.15	0.55	0.91	2.40	0.60
13	**Gazipur-6** (Mail Bazar, Tongi**)**	8.01	2563	0.92	0.12	0.09	1.72	0.37	4.56	0.20
14	**Gazipur-7** (Meghna ghat. Tongi**)**	7.77	3009	2.67	0.34	0.27	1.60	0.48	1.29	0.70
15	**Hazaribagh-1**(Tannery area**)**	6.47	3674	3.90	0.51	0.39	1.90	0.88	1.20	0.76
16	**Hazaribagh-2** (Tannery area**)**	7.91	3790	4.10	0.52	0.40	2.10	0.99	1.99	0.80
17	**Hazaribagh-3** (Tannery area**)**	6.80	3530	3.41	0.43	0.35	1.80	0.77	1.57	0.67
18	**Hazaribagh-4** (Tannery area**)**	6.15	3375	2.90	0.38	0.28	1.71	0.67	1.45	0.90
19	**Hotapara-1** (Givensee Groups**)**	4.16	447	2.30	0.27	0.23	0.44	0.55	1.02	0.59
20	**Hotapara-2** (Givensee Groups**)**	5.57	646	1.90	0.24	0.18	0.11	0.47	0.34	0.21
21	**Hotapara-3** (Givensee Groups**)**	6.10	700	2.10	0.27	0.22	0.27	0.51	0.59	0.43
22	**Keranigonj-1** (Momtaz S M Ltd.**)**	7.05	177	0.79	0.10	0.08	0.57	0.21	0.90	0.40
23	**Keranigonj-2** (Dyeing Ind**.)**	6.88	487	1.34	0.18	0.12	0.52	0.12	2.13	0.73
24	**Keraniganj- 3** (Storage Battery)	2.85	6400	0.99	0.11	0.10	0.09	0.16	0.06	0.03
25	**Keraniganj-4** (M V Corrugation)	6.54	232	1.15	0.14	0.11	0.95	0.12	0.20	0.16
26	**Matuail-1(**Asmat Ali S M Ltd.**)**	9.51	545	0.90	0.11	0.10	0.49	0.18	0.09	0.08
27	**Matuail-2** (Dyeing Industry**)**	10.18	1602	2.10	0.27	0.21	1.20	0.19	0.11	0.15
28	**Matuail-3** (Dastagir S M Ltd.)	7.90	1550	1.50	0.20	0.16	0.64	0.26	3.59	0.38
29	**Savar-1 (**Doel Groups**)**	7.65	920	2.45	0.30	0.25	0.39	0.21	4.27	1.60
30	**Savar-3** (Fazlul Haq S Mills Ltd**.)**	7.90	321	0.38	0.05	0.05	0.48	0.09	1.90	1.12
31	**Savar- 4** (Ofaz U Steel M Ltd**.)**	7.00	355	2.79	0.36	0.26	0.30	0.10	1.54	0.54
32	**Shampur-1(**S S S R M Ltd**.)**	8.19	954	0.73	0.10	0.08	0.98	0.15	0.14	0.22
33	**Shampur-2**(Rupashi Dyeing Ind**.)**	9.54	4510	1.74	0.23	0.18	1.24	0.16	3.76	1.18
34	**Shampur-3** (Kadamtali S R M Ltd.)	8.07	1302	0.89	0.11	0.09	0.85	0.19	3.72	0.33
35	**Tejgaon-1** (Industrial Area**)**	7.91	1310	4.18	0.53	0.40	0.49	0.23	1.15	0.89
36	**Tejgaon-2** (Industrial Area**)**	8.07	1251	3.48	0.46	0.35	0.42	0.23	0.77	0.47
37	**Tejgaon-3** (Industrial Area**)**	8.20	1400	3.20	0.42	0.31	0.44	0.24	0.10	0.30

In addition, during electroplating process in that industry, $Zn(NO_3)_2$ salts were used in salt bridge and the byproduct of $Zn(NO_3)_2$ salts was HNO_3 acid, which might be responsible in the lowering of the pH in soils at Demra- 3. But, the pH at Matuail- 2 (10.18) and Shampur- 2 (9.54) near dyeing industries, and Matuail-1 (9.51) near steel and rerolling mills was found comparatively higher and/or alkaline than others. Because in bleaching processes of textile dyeing industries, considerable amounts of different types of alkali materials were being used. So, textile and dyeing industrial wastes and effluents could provide high pH values in the soils near those industries. The results were in agreement with Khopkar (2008). Ahmed *et al*. (2011) also found considerable amounts of Na, K, Ca and Mg in textile effluents. For that reason, pH of the soils near textile dyeing industries might be higher or alkaline than other areas. Again, the pH of the soils near steel and re-rolling mills was also found high or alkaline, which might be due to the use of $CaCO_3$ or lime in the purification processes of iron from ore in a blast furnace of metal industry, and alkali materials were also used for clearing purpose of metal plants.

And, the lowest mean pH of the soils was found at Hotapara and the highest was found at Matuail. At Hotapara, the major industrial plants were textile dyeing and food and beverage. Halimoon and Yin (2010) revealed that different types of chemicals and dyes were used in textile dyeing industries, in which some were acidic and some were alkaline. And, the acidic natured textile dyes might contribute the acidity of the soils at Hotapara. On the other hand, anaerobic decomposition of the organic wastes from food and beverage and textile dyeing industries might produce organic acids to contribute acidity at Hotapara area. Vega *et al*. (1998) revealed that textile industries use organic substances as raw materials, which undergone anaerobic fermentation processes leading to formation of ammonia and organic acids and hydrolysis of these acid materials caused decrease of pH value. It is noticed that a canal with continuous flowing water is passing across the sampling sites at Hotapara. And, alkali metals and soluble salts might be washing out with flowing water during rainy season or due to heavy downpours or with irrigation and/or seepage water loss and lowered the pH at Hotapara. And, Na, K, Ca and Mg contents in the soils at Hotapara area were found low (Table- 4.3 and Appen.Table- 7).

Among all surveyed areas soil, pH near textile dyeing and metal industries was found high. This is because of the presence of NaOCl, NaOH, Na_2SiO_3, surfactants and sodium phosphate in textile dyes and bleaching materials, which might elevate the pH of soils near dyeing industry (Sultana *et al*., 2009). According to Khopkar (2008), the pH of textile effluents remained in between 7.0 - 11.8, steel foundry 8.5, leather industry 8.0 and viscous rayon industry 8.6-9.4. The pH of the soils of other locations was found more or less within neutral range.

4.1.2.2 *Electrical conductivity (EC)*

The EC of the collected soil samples ranged from 115 µS/cm to 6400 µS/cm. The highest was found at Keranigonj- 3 near lead-storage battery industry, followed by Shampur- 2 near dyeing and Hazaribagh- 2 near tannery industries, but the lowest was recorded at Ashulia- 2 near Horizon Group (Table- 4.3). The mean EC values varied from 283.67 µS/cm at Ashulia to 3592.20 µS/cm at Hazaribagh tannery and the SD ranged from ±75.04 at Tejgaon to ±3053.65 at Keranigonj (Appen.Table- 6). The EC of Shampur- 2, Hazaribagh- 1, Hazaribagh- 3, Hazaribagh- 4, Gazipur- 7 and Gazipur- 6 was 4510 µS/cm, 3674 µS/cm, 3530 µS/cm, 3375 µS/cm, 3009 µS/cm, 2563 µS/cm, respectively which were much higher than other sampling sites. The EC of soils at other sites of the sampling areas was found low. At Keranigonj- 3, substantial amounts of H_2SO_4, Pb, Zn, Cu and Ni were used in battery industry to manufacture lead-acid storage battery. Consequently, Pb, Cu, Zn and sulphate concentrations in the wastewaters near battery industries were found remarkably higher than other investigated areas (Table- 4.1), which might enhance the EC of the soils at that site. On the other hand, EC of the soils at Shampur- 2 near dyeing industry was found high, because textile dyes contained higher amount of minerals, salts and other electrolytes, which might contribute high EC value at that site. Sultana *et al.* (2009) reported high EC in textile effluents. The highest mean and high EC values were found in the soils at all the sites of Hazaribagh tannery area. The results were in agreement with Nuruzzaman *et al.* (1998). They found up to 4.5 dS/m EC in the soils of Hazaribagh tannery area. But, the EC in the soils of Gazipur- 6 near textile industry and Gazipur-7 at Meghna Ghat, Tongi was also found high. Textile industrial wastes and effluents might be responsible to enhance the EC at Gazipur- 6. On the other hand, at Gazipur- 7 dyeing, textile, battery, chemicals, and others industrial wastes were dumped at that site, which might contain substantial amounts of salts to elevate the EC of the soils at that site. The EC values of Tejgaon industrial area were more of less similar with the finding of Chamon *et al.* (2009).

4.1.2.3 *Total organic carbon*

In the soils of the studied areas, organic carbon ranged from 0.29 % at Gazipur- 4 near Metrocem Ispat Industry Ltd. to 4.18% at Tejgaon- 1 inside industrial area (Table- 4.3). The mean values range from 1.07 to 3.62% and the SD varied from ±0.20 at Keranigonj to ±1.30 at Savar (Appen.Table- 6). In the soils at Hazaribagh-1, 2, 3 and 4 and Tejgaon- 2 contained substantially high organic carbon. On the other hand, the highest mean value of organic carbon was found in the soils of Tejgaon industrial area, followed by Hazaribagh and the lowest was recorded at Keranigonj. The contents of organic carbon in a soil depend on the source and the amounts of organic substance incorporated into the soils, their state of decomposition, seasons and soil pH. At Tejgaon area, huge amounts of food and beverage industries are situated, which might contribute ample amounts of organic substances to the soils. And, at the same time, the sampling sites were not favorable or dry enough to decompose the organic matter completely. Likewise, the mean organic carbon content at

Hazaribagh tannery area was also found high, because tannery wastes might contribute substantial amounts of organic matter to nearby soils. But, the state of decomposition was much better than Tejgaon area. The results agreed with the finding of Nuruzzaman *et al*. (1998) and Chamon *et al*. (2009). Chamon *et al*. (2009) found high organic carbon at Tejgaon area and Nuruzzaman *et al*. (1998) observed around 10% organic matter at Hazaribagh tannery area. Due to the presence of dyeing and textile industries, the percent organic carbon in the soil samples of Ashulia, Hotapara and Savar was found slightly higher than other investigated areas. Khopkar (2008) reported that textile and dyeing industries generated substantial amounts of organic substances with their wastes and effluents. On the other hand, organic matter near metal and battery industries was found low, because those industrial plants could not produce organic substances. Simultaneously, due to favorable condition, the rate of decomposition and disappearance of organic matter was found high at other sampling sites.

4.1.2.4 *Total nitrogen*

The total N content in the soils of surveyed areas ranged from 0.04 to 0.53% (Table- 4.3). The mean values ranged from 0.13% at Keranigonj to 0.47% at Tejgaon industrial area and the SD ranged from ±0.02 at Hotapara to ±0.16 at Savar (Appen.Table- 6). The highest content was found at Tejgaon- 1, followed by Hazaribagh- 2 and 1 and the lowest was found at Gazipur- 4 near Metrocem Ispat Mills Ltd. On the other hand, the highest mean value was found at Tejgaon, followed by Hazaribagh and the lowest was found at Keranigonj. But, at Ashulia, Hotapara and Savar, N content was found slightly higher than other locations. A large number of food and beverage and textile dyeing industries were present at Tejgaon area, which might be responsible to contribute high organic substances to the soils at Tejgaon area. Similarly, soils at Hazaribagh, Ashulia, Hotapara and Savar contained higher amounts of N, where tannery and textile industries were the main industries which might contribute substantial amounts of organic substances. And at the same time, higher amounts of organic carbon were also found at those sites. The results were in agreement with Bremer and Bundy (1974) and Nuruzzaman *et al*. (1998). They revealed that the higher N content in top soils associated with the presence of organic matter. There is a close relationship between organic matter and total N content in soils. Due to the random discharge of organic wastes from food and beverage as well as textiles and dyeing industries, total N content at different locations in and around Dhaka was found high. A highly significant positive correlation was found between total nitrogen and organic carbon in soils.

4.1.2.5 *Total phosphorus*

The total phosphorus contents in the soils of the surveyed areas ranged from 0.03% at Gazipur- 4 near Metrocem Ispat Ltd. to 0.40 % at Hazaribagh tannery- 2 near tannery and Tejgaon- 1 inside industrial area (Table- 4.3). The mean concentration ranged from 0.10% at Keranigonj to 0.36 % at Hazaribagh tannery area and the SD ranged from ±0.02 at Keranigonj to ±0.12 at Savar (Appen.Table- 6). At different sites of Hazaribagh and Tejgaon,

total P was also found high. Bremer and Bundy (1974) and Nuruzzaman *et al.* (1998) revealed that the higher P contents in top soils were associated with the presence of organic matter. So, due to the presence of high organic matter, Tejgaon soils might be enriched with phosphorus. It is important to note that P comes to nature from both organic and inorganic sources. Similarly, the average P concentration at Hazaribagh tannery area was also found high. It might be due to the presence of large number of tannery industries at Hazaribagh area, and those tannery industries generated substantial amounts of organic substances and incorporated organic substances to the nearby soils. In addition, substantial amounts of P bearing substances were also used with color pigments in the tanning process of skins and hides, which might also be responsible to enhance P concentration in the soils at Hazaribagh area. The results were in agreement with the recent findings of Ahmed *et al.* (2011). They reported that tannery and textile wastes effluents contained substantial amounts of phosphorus. Like Hazaribagh, the mean P in the soils at Hotapara and Matuail was found higher than other investigated areas, because major industrial plants at those clusters were textile and dyeing.

4.1.2.6 Cationic Composition:

Analytical results of some cations of the collected soil samples are presented in Table- 4.3 and their mean values and SD are presented in Appen.Table- 7.

4.1.2.6.1 *Total sodium*

The Na contents in the soils ranged from 0.09 to 2.10%. The highest concentration was found at Hazaribagh- 2 within tannery industrial area and the lowest was found at Keranigonj- 3 near battery industry (Table- 4.3). The mean contents varied from 0.27 % at Hotapara to 1.88% at Hazaribagh and the SD ranged from ±0.04 at Tejgaon to ±0.56 at Gazipur. The mean values of Na content at Shampur (1.02%), Gazipur (0.90%) and Matuail (0.78%) areas were also found higher than other investigated areas (Appen.Table- 7).

Higher Na concentration was also found at Gazipur- 6 (1.72%) at Mail Bazar Nisat Gate, Gazipur- 7 (1.60 %) at Meghna Ghat Tongi, Hazaribagh- 1(1.90 %), Hazaribagh- 3(1.80%), Hazaribagh- 4(1.71%), Matuail- 2(1.20%) and Shampur- 2(1.24%), where most of the industrial plants were tannery and textile dyeing. Several researchers (TICI, 2005; Zahid *et al.*, 2006; Karim *et al.*, 2013) reported that the sources of Na in the soils at Hazaribagh tannery area were due to the indiscriminate discharge of tannery waste and effluents. And huge amounts of NaCl salts were being used for preserving skins and hides as dehydrating and antiseptic agent in tannery industries. On the other hand, Ahmed *et al.* (2011) reported that textile dyeing effluents contained higher amounts of Na. Similarly, Sultana *et al.* (2009) stated that textile dyes composed of NaOCl, NaOH, Na_2SiO_3, surfactants and sodium phosphate, which might be responsible to escalate Na concentration in the soils near textile dyeing industries. Conversely, in the clearing operation of steel and re-rolling mills, alkali materials were used, which might be associated with the rise in Na near steel and re-rolling

mills. Then again, textile dyeing, spinning, food and beverage, chemicals etc. industries might contribute Na in the soils at different sampling sites. In contrast, Na contents in soils at Hotapara was found the lowest, where the most industrial plants were textile dyeing, while the rain, irrigation and seepage water might wash out the cations from the soils to nearby canal and might reduce its concentration.

4.1.2.6.2 *Total potassium*

Potassium concentration in the soils of the study areas ranged from 0.09 to 0.99%. The highest concentration was found at Hazaribagh tannery- 2, followed by Gazipur- 5 near Haq battery and the lowest was found at Savar- 3 near F H S Mills Ltd. (Table- 4.3). And the mean concentration ranged from 0.13 to 0.83% and the SD varied from ±0.005 at Tejgaon to ±0.38 at Demra (Appen.Table- 7). The highest mean concentration was found at Hazaribagh tannery, followed by Gazipur and the lowest was found at Savar. High potassium content was also found at Gazipur- 2 near Apex tannery and Hazaribagh tannery- 1. Like NaCl, K salts were also used as dehydrating and antiseptic agent in tannery industries. Ahmed *et al.* (2011) observed higher K content in tannery wastes and effluents than textile dyeing. Similarly, Karim *et al.* (2013) also found higher amounts of K in tannery wastes and effluents. On the other hand, K concentration at Gazipur- 5 near Haq battery was found high. To manufacture alkaline batteries, KOH was used as electrolytes, which might be responsible to increase K at that site. High K content was also found at Demra- 4 near Alaksa steel mills Ltd. It is important to mention that in electroplating processes, KCl salts were also used in salt bridge, which might enhance K in the soils near metal and electroplating industries. Potassium at other spots was found low, because of the removal of K by washing with running water and rainfall. A positive correlation was found between Na and K.

4.1.2.6.3 *Total calcium*

Calcium concentration in the soils of the studied areas ranged from 0.06 to 4.27 % (Table- 4.3). The mean contents varied from 0.65% at Hotapara to 2.57% at Savar and the SD ranged from ±0.13 at Demra to ±2.07 at Shampur (Appen.Table- 7). The highest content was found at Savar- 1 near Doel Group, followed by Gazipur- 6 near dyeing industry and the lowest was found at Keranigonj- 3 near lead-storage battery industry. Although, the main industrial plants in Doel Groups at Savar- 3 were textile and dyeing. Likewise, Ca concentrations in the soils at Shampur- 2 near dyeing, Shampur- 3 and Matuail- 3 near metal industries were also found high. As a matter of fact, textile dyeing industrial wastes and effluents contain Ca in their dyes and bleaching agents. On the other hand, in the purification of iron ore and clearing of steel foundries, alkalis were being used. Karim *et al.* (2013) revealed that textile wastes and effluents, tannery waste effluents, food and beverage, purification of iron ore and steel and re-rolling mills were the main sources of Ca in the soils at different industrial sites. So, Ca contents in the soils at Savar- 3 near Doel Group might be high, where textile and dyeing industries were the main industrial plants.

The mean values of Ca contents of Shampur, Gazipur, Hazaribagh and Ashulia were 2.54%, 2.01%, 1.55% and 1.44%, respectively. In fact, at all the spots mentioned above, tannery, textile and dyeing industries were the prime industrial plants. For that reason, the wastes and effluents of textile and dyeing industries might increase the Ca contents in the soils at those sites. On the other hand, due to washing out of Ca with rainfall, irrigation and runoff water to nearby canal, the lowest concentration was found at Hotapara.

4.1.2.6.4 *Total magnesium*

Magnesium concentrations in the soils of the sampling sites ranged from 0.03 to 1.60% (Table- 4.3). The mean concentration varied from 0.20% at Matuail to 1.08% at Savar and the SD ranged from ±0.09 at Hazaribagh to ±0.53 at Savar and Shampur (Appen.Table- 7). The highest concentration was found at Savar- 1 near textile and dyeing industries and the lowest was found at Keranigonj- 3 near battery industry. However, Mg concentration at Shampur- 2 near dyeing industry, Savar- 3 near Fazlul Haq Steel mills Ltd. and Demra- 4 near Alaksa steel mills was also found high. Textile dyeing industrial wastes and effluents contained higher Mg as described by Karim *et al*. (2013). The highest mean value of Mg was found at Savar and the lowest was found at Matuail. On the other hand, Mg concentration at Hazaribagh, Shampur and Gazipur was also found high. The results were in agreement with the finding of Karim *et al*. (2013) and Ahmed *et al*. (2011). Mg is an important constituent of textile dyeing and tannery chemicals. Conversely, for clearing and purification of iron ores and clearing of steel and re-rolling mills, substantial amounts lime and other alkalis were used. For that reason, the soils near those kinds of industries might be enriched with Mg. Although, a large number of textile and dyeing industries were found at Hotapara, but the mean Mg content was found low. It might be due to the removal of Mg from the soils with rainfall, irrigation and running water by a canal passing across the sampling sites at Hotapara. A positive correlation was found between Ca and Mg.

4.1.2.7 Heavy Metal Concentrations:

Heavy metal constitutes an ill-defined group of inorganic chemical hazards, and those most commonly found at contaminated sites are: Pb, Zn, Cd, Cu, and Ni etc. Some heavy metals concentration in the soil samples collected from different industrial areas in and around Dhaka are presented in Table- 4.4 and the mean values and SD are presented in Appen. Table- 8.

4.1.2.7.1 *Zinc*

Zinc is essential in many metalloenzymes, toxic to plants at higher level and the main sources are industrial waste, metal plating and plumbing (De, 2000).

Zinc concentrations in the soils collected from different industrially contaminated areas ranged from 50 to 2136 mg/kg soil (Table- 4.4). The mean concentrations varied from 130

mg/kg at Hotapara to 824.33 mg/kg Matuail and the SD ranged from ±26.66 at Hotapara to ±1000.52 at Demra (Appen.Table- 8).

Table- 4.4: Analytical Results of Some Heavy Metal Contents in Soils Collected from Different Industrial Areas in and Around Dhaka

No.	Locations	Zn (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Cd (mg/kg)
1	**Ashulia-1** (Sahriar Fabrics**)**	55.00	201.00	25.00	38.00	1.80
2	**Ashulia-2** (Horizon Group**)**	250.00	121.00	36.00	51.00	2.70
3	**Ashulia- 3** (Aman Spinning Mills Ltd.)	300.00	127.00	37.00	16.00	3.00
4	**Demra- 1**(Apollo Steel and C S Mills Ltd.)	50.00	406.00	32.00	14.00	1.90
5	**Demra- 2** (Jahir Steel and R M Ltd.)	336.00	212.00	15.00	34.00	2.30
6	**Demra- 3** (I I Tubes Mills Ltd.)	2136.00	303.00	139.00	189.00	1.50
7	**Demra- 4 (**Alaksa Steel and R R Mills**)**	70.00	790.00	10.00	30.00	0.50
8	**Gazipur- 1** (Konabari Industrial Area **)**	59.00	251.00	58.00	10.00	2.40
9	**Gazipur- 2** (Appex Tannery, Tongi**)**	78.00	55.00	45.00	33.00	0.90
10	**Gazipur- 3** (BISIC, Tongi**)**	220.00	390.00	15.00	57.00	1.50
11	**Gazipur-4** (Metrocem Ispat Mills Ltd.**)**	120.00	300.00	215.00	15.00	1.50
12	**Gazipur- 5** (Haq Battery, Tongi**)**	736.00	390.00	90.00	159.00	0.95
13	**Gazipur- 6** (Mail Bazar, Nisad Gate, Tongi)	500.00	430.00	80.00	97.00	3.80
14	**Gazipur- 7** (Meghna Ghat ,Tongi**)**	140.00	395.00	36.00	55.00	2.90
15	**Hazaribag- 1** (Hazaribagh Tannery**)**	55.00	397.00	75.00	78.00	3.50
16	**Hazaribag- 2** (Hazaribagh Tannery**)**	100.00	255.00	36.00	45.00	1.70
17	**Hazaribag- 3** (Hazaribagh Tannery**)**	58.00	250.00	21.00	32.00	4.70
18	**Hazaribagh- 4** (Hazaribagh Tannery**)**	496.00	215.00	79.00	20.00	2.30
19	**Hotapara-1** ((Near Givensee Group**)**	100.00	65.00	42.00	26.00	4.00
20	**Hotapara-2** (Near Givensee Group**)**	139.00	71.00	100.00	36.00	7.00
21	**Hotapara-3** (Near Givensee Group**)**	151.00	87.00	35.00	32.00	5.00
22	**Keranigonj-1** (Momtaz Steel Mills Ltd**.)**	182.00	300.00	65.00	78.00	1.95
23	**Keranigonj-2** (Dyeing Mills**)**	202.00	250.00	50.00	89.00	0.40
24	**Keranigonj- 3** (Storage Battery Ind.**)**	98.00	685.40	28.47	3000.00	0.16
25	**Keraniganj- 4** (M.V. Corrugation Ltd.**)**	500.00	100.00	47.00	109.00	2.00
26	**Matuail-1** (Asmat Ali Steel M Ltd.**)**	865.00	467.00	29.00	106.00	2.40
27	**Matuail-2** (Dyeing Industry**)**	950.00	79.00	18.00	32.00	3.60
28	**Matuail-3** (Dastagir Steel Mills Ltd.**)**	658.00	177.00	47.00	43.00	0.95
29	**Savar- 1** (Doel Group, Ernlima Yearn**)**	98.00	80.00	55.00	26.00	2.10
30	**Savar-3** (Fazlul Haq Steel Mills Ltd.**)**	300.00	200.00	99.00	20.00	3.30
31	**Savar- 4** (Ofaz Uddin Steel Mills, Kornapara)	367.00	85.00	89.00	22.00	2.00
32	**Shampur-1** (Samia Steel Mills Ltd.**)**	236.00	250.00	27.00	290.00	2.85
33	**Shampur-2** (Rupashi Dyeing Mills Ltd**.)**	302.00	384.00	142.00	180.00	6.00
34	**Shampur-3** (Kadamtali Steel Mills Ltd.**)**	365.00	489.00	76.00	480.00	1.90
35	**Tejgaon-1** (Industrial Area**)**	311.00	167.00	39.00	36.00	2.15
36	**Tejgaon-2** (Industrial Area**)**	229.00	89.00	38.00	19.00	1.80
37	**Tejgaon-3** (Industrial Area**)**	300.00	85.00	40.00	16.00	2.01

The highest Zn concentration was recorded at Demra- 3 near I I Tubes Mills Ltd. and the lowest was found at Demra- 1 near Apollo Ispat and Corrugated Sheets Mills Ltd. And the mean concentration at Matuail (824.33 mg/kg), Demra (648 mg/kg) and Shampur (301 mg/kg) soils was found substantially high and much above the permissible limit of Kloke

(1980). On the other hand, Zn contents in the soils at Matuail-1 (865 mg/kg) near steel mills, Matuail-2 (950 mg/kg) near dyeing mills, Matuail-3 (658 mg/kg soil) near steel mills ltd., Shampur-2 (302 mg/kg) near dyeing, Shampur-3 (365 mg/kg) near metal industry, Tejgaon-1(311 mg/kg) inside industrial area, Tejgaon-3 (300 mg/kg) inside industrial area, Ashulia- 3 (300 mg/kg) near Aman spinning, Demra- 2 (336 mg/kg) near steel mills, Gazipur- 6 (500 mg/kg soil) near dyeing mills, Gazipur- 5 (736 mg/kg soil) near Haq battery, Hazaribagh tannery- 4 (496 mg/kg), Keranigonj- 4 (500 mg/kg) near corrugated sheet mills ltd., Savar-3 (300 mg/kg) near steel mills and Savar-4 (367 mg/kg) near Ofaz Uddin steel mills were found above the permissible limit (300 mg/kg) as described by Kloke (1980). Moreover, the mean Zn concentrations in the surveyed areas exhibited the following descending order: Matuail (824.23 mg/kg)> Demra (648 mg/kg)> Shampur (301 mg/kg) > Tejgaon (280 mg/kg > Gazipur (264.71 mg/kg)> Savar (255 mg/kg) >Keranigonj (245.50 mg/kg)> Hazaribagh (177.25 mg/kg)> Ashulia (175.25 mg/kg)> Hotapara (130 mg/kg).

At Demra- 3, in I I Tubes Mills Ltd., GI, SS and MS sanitary tubes and pipes were manufactured by galvanizing and electroplating process. Zn plating involves the electrolytic application of Zn by immersing clean steel or iron parts in a zinc salt solution or melted Zn. This process applies a layer of pure zinc that range from a few microns on cheap hardware compounds to 15 microns or more, but which ultimately enrich Zn in the waste and effluents of that kinds of industries. It might result high Zn concentration in the soils adjacent to I I Tubes Mills Ltd.

On the other hand, huge amounts of dyeing, smelting and steel processing industries were situated at Matuail area, which was associated with the escalation of the highest mean Zn concentration at that area. The mean zinc concentration at Demra was also found high and the SD was also found the highest. Similarly, the mean Zn concentration of Shampur industrial area was also found high. In fact, at Shampur area, a large numbers of steel and re-rolling mills, electroplating and smelting mills and dyeing industries are present.

The mean Zinc content of Gazipur industrial area was found within the permissible limit except Gazipur- 5 near Haq Battery and Gazipur- 6 at Mail Bazar, Nisad Gate near dyeing industry. To manufacture dry cell and alkaline battery, Zn was used as anode which might enhance Zn concentration at Gazipur- 5 near Haq battery. Likewise, at Nisad Gate, a lot of dyeing industries were situated. The results agreed with the findings of Cammarota (1980) and Kashem and Singh (1998). The zinc concentration at Hazaribagh tannery area varied from 55 to 496 mg/kg soil (Table- 4.4) and the average concentration was found 177.25 mg/kg soil. The results were in agreement with Nuruzzaman (1995) and Kashem and Singh (1998).

At Ashulia, Zn concentrations ranged from 55.0 to 300 mg/kg soil. The highest concentration was found at Ashulia- 3 near Aman Spinning, because textile dyes contain substantial amounts of zinc as described by Halimoon and Yin (2010). Similarly, Zn content at Savar

ranged from 98 to 367 mg/kg soil and the highest Zn concentration was found near steel mills. And, at Keranigonj area, Zn concentration ranged from 98 to 500 mg/kg soil. The highest zinc concentration was found in the soils near M.V Corrugation, which might be due to the use of Zn coatings on corrugated sheets. Likewise, Zn concentrations at Tejgaon industrial area ranged from 229 to 311 mg/kg and the mean concentration was 301 mg/kg soil. As a matter of fact, at Tejgaon area, dry cell battery production, printing, metallurgical operation and parchment paper manufacturing were a usual activity, which might contribute Zn to the soils at that area. On the other hand, the lowest mean zinc content was found at Hotapara, where no metal, steel and re-rolling mills were situated.

Occurrence of Zn toxicity has been associated with Zn smelting production practices and these activities add extremely large quantities of Zn to the soil (Lee and Page, 1967). Moon *et al*. (1991) observed that the effluents of machineries, chemicals and metal molding industries are enriched with Zn. Cammarota (1980) reported that Zn was used in manufacturing of dry cell batteries, perchment papers, printing and dyeing of textiles, as a flux in metallurgical operations, wood preservation, agricultural micronutrient fertilizers, insecticides, construction materials etc. According to Basta and Gradwoht (1998), extensive Pb and Zn ore mining and smelting have resulted in contamination of soil. According to Greavy (2005), most Zn is added to soil during steel processing. Many food stuffs contain certain amounts of Zn. During electroplating process or to manufacture sanitary tubes and pipes and to protect them from oxidation, a thin layer of zinc is put on steel and other metals. Larsen *et al*. (1975) and Arora *et al*. (1985) reported that industrial effluents and municipal wastewaters usually contained high amounts of Zn. Kashem and Singh (1998) revealed that the emission of Zn in the tannery industry and the textile dyeing industrial sites led to contamination of soils in the closer vicinity. They found 53 - 477 mg/kg soil Zn around Dhaka near different types of industries.

4.1.2.7.2 *Copper*

Copper comes to the soils and environment from various sources such as batteries, pigments, printing products, chemicals using copper salts and copper catalysts, metal processing products, steel product etc.

Copper concentrations in the soils of the surveyed areas ranged from 55 to 790 mg/kg (Table-4.4). The mean concentration ranged from 74.33 to 427.75 mg/kg and the SD ranged from ±11.37 to ±254.17 (Appen.Table- 8). The highest concentration was found at Demra- 4 near Alaksa Steel Mills Ltd. and the lowest was found at Gazipur- 2 near Apex tannery. The highest mean value was recorded at Demra and the lowest was found at Hotapara and the highest SD was also found at Demra and the lowest was obtained at Hotapara. A very wide range of variation was found between the maximum and the minimum values of Cu concentration in most of the sampling sites.

Copper contents ranged from 121 to 201 mg/kg at Ashulia, 212 to 790 mg/kg at Demra, 55 to 430 mg/kg at Gazipur, 215 to 397 mg/kg at Hazaribagh, 65 to 87 mg/kg at Hotapara, 100 to 685 mg/kg at Keranigonj, 79 to 467 mg/kg at Matuail, 80 to 200 mg/kg at Savar, 250 to 489 mg/kg at Shampur and 85 to 167 mg/kg at Tejgaon (Table- 4.4). The mean Cu concentration showed the following descending order: Demra (427.75 mg/kg) > Shampur (374.33 mg/kg) > Keranigonj (338.85 mg/kg) > Gazipur (315.86 mg/kg) > Hazaribagh (279.25 mg/kg) > Matuail (241 mg/kg) > Ashulia (170 mg/kg) > Savar (121.67 mg/kg) > Tejgaon (113.67 mg/kg) > Hotapara (74.33).

In most of the sampling sites, Cu concentrations were found above the tolerable limit (50 mg/kg) as described by Kloke (1980). Remarkably high Cu concentration was observed at Demra- 4 (790 mg/kg) near Alaksa Steel Mills Ltd., Keranigonj- 3 (685 mg/kg) near lead-storage battery industry, Shampur- 3 (489 mg/kg soil) near steel mills, Matuail- 1 (467 mg/kg) near steel mills, Demra- 1 (406 mg/kg) near Apollo Steel and Corrugated Sheets Ltd, Gazipur- 6 (430 mg/kg soil) near dyeing industry, Hazaribagh tannery-1 (397 mg/kg), Gazipur-3 (390 mg/kg) near BISIC, Tongi, Keranigonj- 1 (390 mg/kg) near Momtaj Steel Mills Ltd, Gazipur- 5 (390 mg/kg) near Haq battery, Demra-3 (303 mg/kg) near I I Tubes Mills Ltd., Gazipur- 7 (395 mg/kg) at Meghna Ghat, Tongi and Gazipur-4 (300 mg/kg) near Metrocem Ispat Ltd. (Table- 4.4). The above results revealed that the steel, corrugated sheet, dyeing, tannery and battery industries etc. were the main sources of Cu to the nearby soils and lands. The results were in accordance with Masud (2007) and Njit (2013). Njit (2013) reported that the source of Cu in the soils were chemicals using copper salts, copper catalysts, metal processing products, and iron ore crushing plants. Similarly, Masud (2007) reported that the main raw materials of steel and re-rolling mills of Bangladesh were derived from ship breaking industries and as a result Cu was found as a byproduct of steel and re-rolling mills. As a matter of fact, in steel and re-rolling mills, iron ores and ship breaking plates were also being used, and Cu was the byproduct of iron ore and ship breaking plates. Wang *et al*. (2005) observed the highest concentration of Zn and Cu in the industrial waste and sewage sludge. On the other hand, a study conducted by Kahsem and Singh (1998) on different sites in and around Dhaka and revealed that the release of Cd, Cu, Mn, Ni, Pb and Zn in tannery and textile dyeing industrial sites led to contamination of soils in the closer vicinity. They identified 28-217 mg/kg soil Cu in the investigated areas in and around Dhaka. Similarly, Duval *et al*. (1980) reported that the tannery industries were discharging significant amounts of Ag, Cd, Cu, Pb and Zn as well.

In fact, due to unplanned industrialization, textile, dyeing, steel and re-rolling, battery, chemicals and electroplating industries were very closely situated in and around Dhaka. The waste and effluents of those kinds of industries had enriched the metal concentration to nearby soils through running waters or effluent and solid waste disposal or dumping to nearby lands. Halimoon and Yin (2010) found Pb, Zn, Cd and Cu in color pigments and

textile dyes. Likewise, Kashem and Singh (1998) found the highest amounts of total and extractable Cu in the textile and dyeing industrial areas.

According to Wright *et al*. (1955), Cu is one of the least mobile of the trace elements, and accumulates in the surface soil from the source. On the other hand, Moon *et al*. (1991) carried out an investigation on Pb, Cd, Zn and Cu levels in top soils of an industrial complex surrounded by many types of industries and found that these metals contributed significantly towards environmental contamination resulting from industrial operations. Likewise, Duce and Windom (1976) reported that the major sources of Cu were from Cu compounds and Cu chelates in agriculture, smelting for Cu, iron and steel production and coal combustion from the industries. The extractable Cu in the cultivated layers of soils was increased by the application of untreated municipal wastewaters as revealed by Schirado *et al*. (1986).

4.1.2.7.3 *Nickel*

Electroplating, nickel alloy production, batteries, ship building, surgical implants and textiles etc. are the main sources of Ni in the soils and environment.

Nickel contents in the soils of the studied areas varied from 10 mg/kg at Demra- 4 near Alaksa steel and re-rolling mills to 215 mg/kg at Gazipur- 4 near the soils of Metrocem Ispat Mills Ltd. (Table- 4.4). The mean concentration ranged from 31.33 mg/kg at Matuail to 81.67 mg/kg at Shampur and the SD ranged from ±1.0 at Tejgaon to ±65.99 at Gazipur (Appen.Table- 8).

At different locations, Ni concentration ranged from 25 to 37 mg/kg at Ashulia, 10 to 139 mg/kg at Demra, 15 to 215mg/kg at Gazipur, 21 to 79 mg/kg at Hazaribagh, 35 to 100 mg/kg at Hotapara, 28.47 to 65 mg/kg at Keranigonj, 18 to 47 mg/kg at Matuail, 55 to 99 mg/kg at Savar, 27 to 142 mg/kg at Shampur and 38 to 40 mg/kg at Tejgaon. On the other hand, the mean Ni contents in the investigated areas exhibited the following descending order: Shampur (81.67 mg/kg) > Savar (81 mg/kg) > Gazipur (77 mg/kg) > Hotapara (59 mg/kg) > Hazaribagh (52.75 mg/kg) > Demra (48.75 mg/kg) > Keranigonj (47.73 mg/kg) > Tejgaon (39.0 mg/kg) > Ashulia (31.75 mg/kg) > Matuail (31.33 mg/kg). The mean Ni concentration at Shampur, Savar, Gazipur, Hotapara, Hazaribagh and Keranigonj was found above permissible limit (50 mg/kg soil) as described by Kloke (1980). The highest Ni content was found at Gazipur- 4 (215 mg/kg) near Metrocem Ispat. High Ni concentration was also found at Demra- 3(139 mg/kg) near I I Tubes and Pipe Mills Ltd., Shampur- 2(142 mg/kg) near dyeing industry, Savar- 3(99 mg/kg) near Fazlul Haq Steel Mills Ltd., Hotapara- 2 (100 mg/kg) near Givensee Groups, Gazipur- 5 (90 mg/kg) near Haq battery, Gazipur- 6(80 mg/kg) at Mail Bazar near dyeing industry, Hazaribagh- 4(79 mg/kg) and Hazaribagh- 1(75 mg/kg).

As a matter of fact, in most of the steel and rerolling mills, ship breaking sheets are being used as raw material in Bangladesh. And, Ni was found an indispensible byproduct from

those kinds of industries, which ultimately contaminated the soils near the steel and rerolling mills. On the other hand, Ni is an important ingredient of steel. So, it is very usual to see the soils rich in Ni near steel industry. Khodadoust *et al*. (2004) reported that the most common use of Ni as an ingredient of steel and other metal products. Njit (2013) stated that the sources of Ni in soils were from steel, chemicals and other metal products.

Again, Ni concentration was found high at Demra- 3 near I I Tubes Ltd., where Ni salts were used to manufacture Ni coated sanitary tubes and pipes by electroplating process in that industry. Besides, mild steel and stainless steel sanitary pipes, tubes and rods were also manufactured in that industry. The results were also in agreement with Chamon *et al*. (2009). They found high Ni concentration near electroplating industrial plants. On the other hand, Ni concentration in the soils at Gazipur- 5 near Haq battery was also found high, which might be due to the fact that Ni salts were used as electrolytes to manufacture Ni-Cd dry cell battery in Haq Battery Industries Ltd., Gazipur. Moreover, due to the presence of steel, textiles, battery and tannery industries, Ni content at Savar, Hazaribagh, Keranigonj and Gazipur was found high as well. The mean Ni concentration in the Tejgaon industrial area agreed well with the findings of Chamon *et al*. (2005). Except in few cases, Ni concentrations in and around Dhaka were in accordance with the finding of Kashem and Singh (1998).

Compel and Nikel (2006) reported that Ni content in world soils varied from 3 to 1000 mg/kg and the mean value was 22 mg/kg. And the major sources of Ni in soils were industrial waste and effluents, lime, fertilizer, and sewage sludge (McIlveen and Neghsanti, 1994). The tolerable limit of Ni in soil is 50 mg/kg (Kloke, 1980). Chamon *et al*. (2009) reported that industries like battery, chemical manufacturing, electrical and electronic, metal finishing, mining, paint and dye, textiles, pharmaceuticals and pesticides etc. discharged heavy metal like Ni in their effluents and wastes.

It needs to mention that the major source of Ni in soils of Bangladesh are poorly treated effluents that is discharged from ceramics, steel and alloys and other metal processing industries. Khodadoust *et al*. (2004) also revealed that the major sources of Ni contamination in the soil were the metal plating industries, combustion of fossil fuels and Ni mining and electroplating. Conversely, Wang *et al*. (2005) found substantial amounts of Ni in sewage sludge derived from municipal and industrial wastes. Similarly, Larsen *et al*. (1975) and Arora *et al*. (1985) also stated that industrial effluents and municipal wastewater usually contain high amounts of Ni. Kashem and singh (1998) reported that textile dyeing and tannery industries contributed Ni contamination of soils in the immediate vicinity of industrial sites in and around Dhaka. They revealed that Ni content ranged from 25 to 112 ppm at different industrial sites around Dhaka.

4.1.2.7.4 *Lead*

Lead is relatively immobile metal. It adds to the soils and environment from different sources such as fossil fuels, coal mining and combustion, industrial emission, aerosols and pesticides etc. The main sources of Pb are from batteries, pigment and printing products. Background concentration of Pb ranged from 12 - 20 mgkg[-1] (Singh and Steinnes, 1994) and the tolerable total concentrations in soils is 100 mg/kg (Kloke, 1980).

Pb contents in soils of the sampling sites ranged from 10 mg/kg at Gazipur- 1 Konabari industrial area to 3000 mg/kg at Keranogonj- 3 near lead- storage battery industry (Table- 4.4). The mean concentration ranged from 22.67 mg/kg at Savar to 819.00 mg/kg at Keranigonj and the SD varied from ±3.05 at Savar to ±1454.06 at Keranigonj (Appen.Table- 8).

Pb content in the soils at different areas varied from 16 to 51 mg/kg Ashulia, 14 to 189 mg/kg Demra, 10 to 159 mg/kg at Gazipur, 20 to 78 mg/kg at Hazaribagh, 26 to 36 mg/kg at Hotapara, 78 to 3000 mg/kg at Keranigonj, 32 to 106 mg/kg at Matuail, 20 to 26 mg/kg at Savar, 180 to 480 mg/kg at Shampur and 16 to 36 mg/kg at Tejgaon.

The highest Pb concentration was found at Keranigonj- 3 near lead-storage battery industry (3000 mg/kg soil). Higher amounts of Pb contents were found at Shampur- 3(480 mg/kg) near Kadamtali Steel and Rerolling Mills Ltd., Matuail- 1 (106 mg/kg) near ASM Ltd., Shampur- 1 (290 mg/kg) near Samia Steel Mills Ltd., Shampur- 2 (180 mg/kg) near Rupashi Dyeing Industry, Demra- 3 (189 mg/kg) near I I Tubes Mills Ltd. and Gazipur- 5 (159 mg/kg) near Haq Battery. On the other hand, the mean concentration exhibited the following descending order: Keranigonj (819 mg/kg)> Shampur (316.67 mg/kg) > Demra (66.75 mg/kg) > Gazipur (60.80 mg/kg)> Matuail (60.33 mg/kg)> Hazaribagh (43.75 mg/kg) > Hotapara (31.33 mg/kg) > Ashulia (30.0 mg/kg) > Tejgaon (23.67 mg/kg) > Savar (22.67 mg/kg). The highest mean Pb concentration was found at Keranigonj industrial area, followed by Shampur and the lowest was found at Savar. The mean values of Pb concentrations at Demra, Matuail, Gazipur Hazaribagh, Hotapara, Tejgaon and Ashulia and Savar were found within the permissible limit as described by Kloke (1980).

Because of the presence of lead-storage battery industries, the highest and substantially high Pb concentration was found at Keranigonj- 3 near battery industry. Due to the same reason, the mean concentration was also found high at Keranigonj area. On the other hand, Pb concentration at Shampur area was found high, where steel and re-rolling metal industries were the main industrial plants. At other locations near metal, steel and re-rolling mills, battery, tannery, textile dyeing industries of the surveyed areas, Pb contents were found high. The results of present investigation were analogous with the findings of several researchers. Eick *et al*. (1999) reported that the main sources of Pb were the effluents from the storage battery, industry, mining and smelting of Pb ores, metal plating and finishing operations, casting metal products and chemicals etc. On the other hand, Chaney and Ryan (1994),

Paivoke (2002) and Setyorini *et al*. (2013) found that sewage sludge from the textile industries contained high concentration of Pb. Kashem and Singh (1998) found that Pb contents in the contaminated soils around Dhaka city ranged from 17- 99 mg/kg soil. Similarly, Nuruzzaman *et al*. (1998) found 20.5 - 68.5 mg/kg Pb at Hazaribagh tannery and Chamon *et al*. (2005) reported the mean Pb concentration in the soils of Tejgaon industrial area was 136 mg/kg. Larsen *et al*. (1975), Arora *et al*. (1985) and Gupta *et al*. (1986) reported that industrial effluent and municipal wastes usually contain substantial amounts of Pb and their continuous use on agricultural land might result in metal accumulation in surface soil. Angelon and Bini (1992) found 1000 - 4000 mg/kg Pb in steel dusts and roadside soils. Conversely, Duval *et al*. (1980) reported that tannery industries were discharging significant amounts of Pb.

4.1.2.7.5 *Cadmium*

Cadmium is more mobile than any other heavy metals due to its weak affinity for soil colloids and hence is easily transferred to the crops (Alloway, 1995).

Cadmium contents in the soils of the sampling sites ranged from 0.16 mg/kg soil at Keranigong- 3 near lead-storage battery industry to 7.0 mg/kg soil at Hotapara- 2 near Givensee Group of Industries (Table- 4.4). The mean concentration varied from 1.13 mg/kg at Keranigonj to 5.33 mg/kg at Hotapara and the SD ranged from ±0.18 at Tejgaon to ±2.15 at Shampur (Appen.Table- 8).

Cd contents in soils at different locations ranged from 1.80 to 3.0 mg/kg at Ashulia, 0.50 to 2.30 mg/kg at Demra, 0.90 to 3.80 mg/kga at Gazipur, 1.70 to 4.70 mg/kg at Hazaribagh, 4 to 7 mg/kg at Hotapara, 0.16 to 2 mg/kg at Keranigonj, 0.95 to 3.60 mg/kg at Matuail, 2.0 to 3.30 mg/kg at Savar, 1.90 to 6.0 mg/kg at Shampur and 1.80 to 2.15 mg/kg at Tejgaon. And the mean concentration exhibited the following order: Hotapara (5.33 mg/kg) > Shampur (3.58 mg/kg)> Hazaribagh (3.05 mg/kg)> Ashulia (2.50 mg/kg)> Savar (2.47 mg/kg)> Matuail (2.32 mg/kg> Tejgaon (1.97 mg/kg)> Gazipur ((1.83 mg/kg)> Demra (1.55 mg/kg)> Keranigonj (1.13 mg/kg).

The highest Cd concentration was found at Hotapara-2 (7.0 mg/kg) near Givensee Group followed by Shampur- 2 (6.0 mg/kg) near dyeing, Hotapara- 3 (5.0 mg/kg) near Givensee Group and the lowest was found at Keranigonj- 3 near lead-storage battery industries. On the other hand, Cd concentration at Hazaribagh tannery- 3 (4.7 mg/kg), Hotapara- 1 (4.0 mg/kg) near Givensee Group, Gazipur- 5 (3.80 mg/kg) near textile dyeing, Hazaribagh tannery- 1 (3.50 mg/kg), Savar- 3 (3.30 mg/kg) near Fazlul Haq Steel Mills Ltd. and Ashulia- 3 (3.0 mg/kg) near Aman Spinning Mills Ltd. was also found above the permissible limit of Kloke (1981). At other locations of the surveyed areas such as Gazipur- 7 (2.90 mg/kg) at dumping site of industrial wastes, Shampur-1(2.85 mg/kg) near Metal industry, Matuail- 2 (2.60 mg/kg) near dyeing, Tejgaon- 1 (2.15 mg/kg) inside industrial area, Demra-2 (2.30 mg/kg) near Jahir Steel and Rerolling Mills Ltd., and, Hazaribagh tannery- 4 (2.30 mg/kg), and

Savar- 1 (2.2 mg/kg) near Doel textile and dyeing industries, Cd concentration was found moderate but within the tolerable limit. The highest mean Cd concentration was found at Hotapara industrial area. Textile dyes and phosphate and Zn containing fertilizers might be associated with the escalation of Cd levels in the agricultural soils at Hotapara area. And, it was evident from the above results that soils near textile and dyeing, tannery and metal industries were rich in Cd.

The results corroborate with the findings of several authors. Halimoon and Yin (2010) stated that heavy metal like Cd is widely used for production of color pigments of textile dyes. On the other hand, Chandran *et al*. (2012) and Njit (2013) reported that small industries like textile and synthetic chemicals, photo- processing, jewllery, metallurgical products, ceramics, electroplating products, photographic products, pigments, metal industry, ship breaking industries might contribute high Cd in soils near the industries. In agriculture soils, atmospheric deposition (Keller and Schulin, 2003) is known as a major source of Cd input. In paddy fields, irrigation water is another source, where Cd continuously loads into soil (Ibaraki *et al*., 2009). Similarly, Wuana *et al*. (2010) reported that Cd was used in pigments, stabilization of polyvinyl chloride, in alloys and electronic compounds. Conversely, Campbell (2006) stated that Cd was produced as an inevitable byproduct of Zn and occasionally during Pb refining. Then again, OECD (1994) and Wang (2005) also stated that sewage sludge might also contribute Cd to the soil. Kashem and Singh (1998) investigated different industrial sites around Dhaka and found 0.1-1.8 mg/kg Cd. Chamon *et al*. (2005) found 2.5 mg/kg Cd in the soils at Tejgaon areas. Koch (1989) found Cd in textile and coatings, electronics and autos. On the contrary, Shabnam *et al*. (2009) found high Cd in tannery wastes and effluents at Hazaribagh.

The mean Cd concentration of agricultural soils lies in the range from 0.10 to 1.0 mg/kg (Jackson and Alloway, 1992) and the background concentration varied from 0.01 to 0.20 mg/kg (Singh and Steinnes, 1994) and the tolerable concentration was 3 mg/kg soil (Kloke, 1980). According to Cook and Marrow (1995), the raw materials for iron and steel production contain approximately 0.1 to 5.0 mg/kg of Cd, while those of the cement production contain about 2.0 mg/kg of Cd, fossil fuels contain 0.5 to 1.5 mg/kg Cd, but phosphate fertilizers contain from 10 to 200 mg/kg Cd.

4.1.3 Contaminated Vegetables and other Crops:

Environmental pollution due to anthropogenic activities altered the environment throughout the world like mining, industry and agriculture (Wang *et al*., 2008). Information regarding the accumulation of heavy metals in vegetables in industrially polluted areas of Bangladesh is scarce. And data regarding the extent of contamination of various vegetables and crops by heavy metals at different industrially polluted areas are also limited. But, such information is vital for the production of quality vegetables as well as healthy food stuffs.

The mineral nutrients such as N, P, K, Ca, Mg and Na and the heavy metals such as Zn, Cu, Ni, Pb and Cd concentration in some common leafy vegetables and crop plants such as Lal sak, Kalmi sak, Spinach, Grasses and Rice collected from different industrial areas are presented in Table- 4.5 and the mean values and SD of those nutrients and metals in different vegetables and crops are presented in Appen.Table- 9.

4.1.3.1 *Mineral Nutrition:*

The nutrient elements such as N, P, K, Na, Ca, and Mg content in the Kalmi sak ranged from 1.18 to 3.67%, 0.13 to 0.45%, 0.11 to 1.02%, 1.02 to 2.81%, 0.45 to 2.10% and 0.14 to 0.52%, respectively (Table- 4.5). The mean concentrations of N, P, K, Ca, Mg and Na content in the Kalmi sak was 2.37, 0.30, 1.57, 0.90, 0.33 and 0.71%, respectively and the SD of N, P, K, Ca, Mg and Na in Kalmi sak was found ±0.66, ±0.10, ±0.62, ±0.46, ±0.13 and ±0.29, respectively (Appen.Table - 9).

N, P, Na, K, Ca and Mg content in Spinach ranged from 2.0 to 2.98%, 0.17 to 0.33 %, 0.23 to 0.78%, 1.51 to 2.38%, 0.42 to 1.80% and 0.18 to 0.45%, respectively (Table- 4.5). The mean values of N, P, K, Ca, Mg and Na in Spinach was 2.65, 0.28, 1.87, 0.97, 0.32 and0.54%, respectively and the SD of N, P, K, Ca, Mg and Na in Spinach was found ±0.28, ±0.11, , ±0.34, ±0.64, ±0.10 and ±0.21,respectively (Appen.Table- 9).

Lal sak is widely cultivated vegetables in Bangladesh. The N, P, Na, K, Ca, and Mg contents in Lal sak ranged from 2.32 to 2.99 %, 0.08 to 0.40%, 0.29 to 1.01%, 1.15 to 2.88%, 0.63 to 3.5% and 0.18 to 0.99 %, respectively (Table- 4.5). The mean contents of N, P, K, Ca, Mg and Na in Lal sak was 2.66, 0.27, 1.56, 1.66, 0.61 and 0.66%, respectively and the SD of N, P, K, Ca, Mg and Na was ±0.23, ±0.12, ±0.66, ±1.06 and ±0.31 and ±0.28, respectively (Appen.Table- 9).

In Rice crops, the nutrients such as N, P, Na, K, Ca and Mg contents ranged from 1.9 to 2.32%, 0.19 to 0.32%, 0.31 to 0.77%, 0.99 to 1.74%, 0.23 to 1.15% and 0.23 to 0.29 %, respectively (Table- 4.5). The mean values of N, P, K, Ca, Mg and Na content in Rice were 2.12, 0.27, 1.25, 0.60, 0.26 and 0.61%, respectively and the SD of N, P, K, Ca, Mg and Na in rice was ±0.21, ±0.07, ±0.42, ±0.49 and ±0.03 and ±0.26, respectively (Appen.Table- 9).

In Grasses, N, P, Na, K, Ca and Mg contents ranged from 1.55 to 2.74%, 0.15 to 0.35%, 0.35 to 1.01%, 1.04 to 1.78%, 0.25 to 5.79% and 0.18 to 1.09%, respectively (Table- 4.5). The mean concentration of N, P, K, Ca, Mg and Na content in Grasses was 2.20, 0.24, 1.36, 1.66, 0.47 and 0.73%, respectively and the SD of N, P, K, Ca, Mg and Na in Grass was ±0.45, ±0.07, , ±0.26, ±1.58, ±0.27 and ±0.24, respectively (Appen.Table- 9).

Table- 4.5: Mineral Nutrition and Heavy Metal Concentrations in Vegetables and Other Crops Collected from Different Industrial Areas in and Around Dhaka

No.	Locations	Vegetables and other Crops	Mineral Nutrition						Heavy Metal Concentrations				
			N (%)	P (%)	Na (%)	K (%)	Ca (%)	Mg (%)	Zn (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Cd (mg/kg)
1	**Ashulia-1 (**Sahriar Fabrics**)**	**Kalmi sak**	1.18	0.13	0.92	1.78	0.50	0.14	40.00	30.00	6.40	3.85	1.78
2	**Ashulia-2 (**Horizon Group**)**	**Grass**	2.69	0.15	0.75	1.55	1.40	0.37	150.00	38.00	6.00	2.23	0.90
3	**Ashulia- 3 (**Aman Spinning Mills Ltd**.)**	**Spinach**	2.90	0.19	0.65	1.81	1.80	0.37	205.00	35.00	8.20	2.90	1.99
4	**Demra- 1 (**Apollo Ispat and C S M Ltd**.)**	**Rice**	2.32	0.30	0.75	1.03	0.23	0.23	45.00	37.00	6.50	1.90	1.50
5	**Demra- 2 (**Jahir Steel Mills Ltd.**)**	**Lal sak**	2.52	0.40	0.55	1.22	1.20	0.50	400.00	30.00	3.50	12.00	1.20
6	**Demra-3 (**I ITubes Mills Ltd.**)**	**Lal sak**	2.32	0.38	1.01	1.15	1.33	0.53	1684.00	61.00	30.70	7.00	2.73
7	**Demra- 4 (**Alaksa Steel Mills Ltd.**)**	**Grass**	1.90	0.30	0.65	1.45	1.67	0.41	50.00	230.00	1.50	1.80	0.30
8	**Gazipur-1 (**Konabari Industrial Area**)**	**Grass**	2.52	0.20	1.01	1.35	1.71	0.61	50.00	52.00	3.30	0.67	1.95
9	**Gazipur- 2 (**Appex Tannery, Tongi**)**	**Lal sak**	2.99	0.08	0.79	1.16	3.50	0.95	130.00	22.00	10.00	3.50	0.50
10	**Gazipur- 3 (**BISIC, Tongi**)**	**Grass**	2.74	0.19	0.97	1.41	1.28	1.09	200.00	74.00	8.50	2.91	0.99
11	**Gazipur-4 (**Metrocem Ispat Ltd., Tongi**)**	**Grass**	2.04	0.19	0.99	1.21	2.34	0.59	90.00	40.00	35.60	0.95	0.99
12	**Gazipur-5 (**Haq Battery, Tongi**)**	**Kalmi sak**	1.97	0.26	1.02	1.44	0.54	0.17	720.00	27.00	17.90	2.20	0.75
13	**Gazipur- 6 (**Mail Bazar, N G., Tongi**)**	**Kalmi sak**	2.43	0.21	0.91	1.03	0.82	0.39	550.00	28.00	15.50	1.90	3.30
14	**Gazipur-7 (**Meghna Ghat, Tongi-1**)**	**Kalmi sak**	1.85	0.38	0.90	1.67	1.12	0.52	150.00	31.00	8.50	2.77	1.60
15	**Gazipur- 8 (**Meghna Ghat, Tongi- 2**)**	**Lal sak**	2.72	0.21	0.89	1.40	1.00	0.49	120.00	33.00	7.90	6.00	1.45
16	**Hazaribag-1 (**Hazaribagh Tannery Area**)**	**Grass**	2.61	0.23	0.85	1.24	0.25	0.20	50.00	26.00	7.70	3.40	3.10
17	**Hazaribag-2 (**Hazaribagh Tannery Area**)**	**Kalmi sak**	3.26	0.19	0.49	0.85	1.00	0.48	129.00	14.00	5.80	14.00	1.58
18	**Hazaribag-3 (**Hazaribagh Tannery Area**)**	**Grass**	2.64	0.17	0.88	1.09	2.53	0.35	65.00	67.00	16.10	4.20	1.54
19	**Hazaribagh-4 (**Hazaribagh Tannery Area**)**	**Kalmi sak**	2.93	0.24	0.83	1.09	2.10	0.35	277.00	26.00	11.30	3.40	3.10
20	**Hotapara-1 (**Near Givensee Group**)**	**Kalmi sak**	2.17	0.39	0.33	1.98	0.51	0.36	121.00	35.00	9.00	4.20	4.20
21	**Hotapara-2 (**Near Givensee Group**)**	**Rice**	1.90	0.32	0.31	1.74	0.42	0.27	100.00	15.00	6.80	2.70	3.70
22	**Hotapara-3 (**Near Givensee Group**)**	**Spinach**	2.50	0.29	0.23	2.38	0.61	0.31	159.00	23.00	11.00	3.90	3.90
23	**Keranigonj-1 (**Momtaz Steel Mills Ltd**.)**	**Kalmi sak**	3.67	0.39	0.73	1.02	0.83	0.38	170.00	26.00	10.50	2.89	2.10
24	**Keranigonj-2 (** Dyeing Industry **)**	**Grass**	2.28	0.17	0.79	1.04	5.79	0.72	190.00	20.00	8.60	6.00	1.46
25	**Keraniganj-4 (**M.V.Corrugations Ltd.**)**	**Lal sak**	2.65	0.23	0.45	1.55	2.30	0.99	390.00	41.00	5.50	4.00	2.44
26	**Matuail-1 (**Asmat Ali Steel Mills Ltd.**)**	**Spinach**	2.85	0.33	0.78	2.03	0.51	0.18	389.50	11.90	4.40	9.00	3.70
27	**Matuail-2 (**Dyeing Industry**)**	**Kalmi sak**	2.87	0.45	0.11	2.51	0.74	0.25	481.30	27.30	7.70	5.40	3.90
28	**Matuail-3 (**Dastagir Steel Mills Ltd**.)**	**Grass**	1.81	0.33	0.40	1.06	0.43	0.44	200.00	77.00	5.11	4.50	0.70
29	**Savar-1 (**Doel Group & Ernlima Yarn**)**	**Spinach**	2.00	0.17	0.44	1.51	1.50	0.45	71.00	29.00	6.40	2.09	1.21
30	**Savar-3 (**Fazlul Haq Steel Mills Ltd**.)**	**Rice**	2.13	0.19	0.77	0.99	1.15	0.29	56.00	44.00	14.69	1.67	1.90
31	**Savar- 4 (**Ofaz Uddin Steel Mills Ltd**.)**	**Kalmi sak**	2.19	0.20	0.81	1.07	1.20	0.22	255.00	34.00	9.10	0.89	1.90
32	**Shampur-1 (**Samia Steel Mills Ltd.**)**	**Kalmi Sak**	1.90	0.41	0.36	2.81	0.60	0.20	275.30	77.00	14.20	54.00	4.00
33	**Shampur-2 (**Rupashi Dyeing Mills Ltd.**)**	**Grass**	1.55	0.35	0.42	1.78	0.43	0.19	261.80	98.10	14.00	14.00	3.30
34	**Shampur-3 (**Kadamtali Steel Mills Ltd**.)**	**Kalmi sak**	2.10	0.30	0.78	1.99	0.47	0.34	266.37	11.20	7.80	21.00	2.50
35	**Tejgaon-1 (**Industrial Area**)**	**Grass**	1.64	0.31	0.35	1.74	0.40	0.18	264.30	16.00	7.70	1.90	1.04
36	**Tejgaon-2 (**Industrial Area**)**	**Spinach**	2.98	0.44	0.58	1.64	0.42	0.30	351.80	10.00	9.50	2.60	1.90
37	**Tejgaon-3 (**Industrial Area**)**	**Lal sak**	2.78	0.33	0.29	2.88	0.63	0.18	268.30	59.40	24.50	2.20	2.75

In Rice crops, the nutrients such as N, P, Na, K, Ca and Mg contents ranged from 1.9 to 2.32%, 0.19 to 0.32%, 0.31 to 0.77%, 0.99 to 1.74%, 0.23 to 1.15% and 0.23 to 0.29 %, respectively (Table- 4.5). The mean values of N, P, K, Na, Ca, and Mg content in Rice were 2.12, 0.27, 0.61, 1.25, 0.60 and 0.26%, respectively and the SD of N, P, Na, K, Ca and Mg in rice was ±0.21, ±0.07, ±0.26, ±0.42, ±0.49 and ±0.03, respectively (Appen.Table-9).

In Grasses, N, P, Na, K, Ca and Mg contents ranged from 1.55 to 2.74%, 0.15 to 0.35%, 0.35 to 1.01%, 1.04 to 1.78%, 0.25 to 5.79% and 0.18 to 1.09%, respectively (Table- 4.5). The mean concentration of N, P, Na, K, Ca, and Mg content in Grasses was 2.20, 0.24, 0.73, 1.36, 1.66 and 0.47%, respectively and the SD of N, P, Na, K, Ca and Mg in Grasses was ±0.45, ±0.07, ±0.24, ±0.26, ±1.58 and ±0.27, respectively (Appen.Table-9).

Mineral nutrient elements such as N, P, K, Ca, Mg and Na concentrations in vegetables and crop plants collected from different metal contaminated areas varied among different crops and also among different varieties of the same cultivar and also different sites. It might be due to the nutrient status and their availability, heavy metals status and their availability to cause toxic effect on nutrient accumulation by different crops at different sites of the sampling areas. The availability of nutrient elements depend on soil pH, organic matter status, presence of different heavy metals and their status in soils and their effect on crops and also other chemical and environmental factors prevailed in those soils. Zhang *et al.* (1991) reported that the availability heavy metals and their effect are directly related to the plant itself. Many researchers found significant difference concerning nutrient utilization efficiency of different crops. Karim *et al.* (2012) and Chatzistathis *et al.* (2012) also reported that nutrient utilization efficiency of different plant species differed among genotypes (cultivars) of the same plant species or among different species.

4.1.3.2 *Heavy metal concentrations and the extent of contamination:*

The heavy metals such as Zn, Cu, Ni, Pb and Cd concentration in different vegetables and crop plants such as Lal sak, Kalmi sak, Spinach, Grasses and Rice collected from different industrially contaminated areas are presented in Table-4.5 and the mean values and SD of different metals are presented in Appen.Table- 9.

The toxic heavy metals such as Zn, Cu, Ni, Pb and Cd contents in Kalmi sak ranged from 40 to 720 mg/kg, 11.20 to 77 mg/kg, 6.4 to 17.90 mg/kg, 0.89 to 14 mg/kg and 0.75 to 4.2 mg/kg, respectively (Table- 4.5). The mean values of Zn, Cu, Ni, Pb and Cd were found in the following descending order: Zn (286.25 mg/kg) > Cu (30.54 mg/kg) > Ni (10.31 mg/kg) > Pb (9.70 mg/kg) > Cd (2.56 mg/kg). And the SD of Zn, Cu, Ni, Pb and Cd of Kalmi sak was ±200.47, ±16.26, ±3.76, ±15.14, ±1.12, respectively (Appen.Table- 9).

The heavy metals such as Zn, Cu, Ni, Pb and Cd concentration in Spinach ranged from 71 to 389.5 mg/kg, 10 to 35 mg/kg, 4.4 to 11.0 mg/kg, 2.09 to 9.0 mg/kg and 1.21 to 3.9 mg/kg, respectively (Table- 4.5). The mean concentration in Spinach exhibited the following

descending the order: Zn (235.26 mg/kg)> Cu (21.78 mg/kg)> Ni (7.90 mg/kg)> Pb (4.10 mg/kg)> Cd (2.54 mg/kg). And the SD of Zn, Cu, Ni, Pb and Cd of Spinach was ±133.30 ±10.88, ±2.58, ±2.82 and ±1.92, respectively (Appen.Table- 9).

And, the metals such as Zn, Cu, Ni, Pb and Cd concentrations in Lal sak ranged from 120 to 1684 mg/kg, 22 to 61 mg/kg, 3.50 to 30.70 mg/kg, 2.2 to 12 mg/kg and 0.50 to 2.75 mg/kg, rsepectively (Table- 4.5). And the mean values exhibited the followed order: Zn (498.72 mg/kg)> Cu (41.07 mg/kg)> Ni (13.68 mg/kg)>Pb (5.70 mg/kg)>Cd (1.85 mg/kg). And the SD of Zn, Cu, Ni, Pb and Cd was ±593.12, ±16.03, ±11.17 ±3.50 and ±0.93, respectively (Appen.Table- 9).

And the heavy metals such as Zn, Cu, Ni, Pb and Cd concentrations in Rice varied from 45 to 100 mg/kg, 15 to 44 mg/kg, 6.5 to 14.69 mg/kg, 1.67 to 2.7 mg/kg and 1.50 to 3.7 mg/kg, respectively (Table- 4.5) and the mean metal concentration showed the following descending order: Zn (67 mg/kg), Cu (32 mg/kg), Ni (9.33 mg/kg), Pb (2.09 mg/kg) and Cd (1.40 mg/kg). And the SD of Zn, Cu, Ni, Pb and Cd was ±29.10, ±15.13, ±4.64, ±0.54 and ±0.37, respectively (Appen.Table- 9).

But, the metals such as Zn, Cu, Ni, Pb and Cd concentrations in Grasses ranged from 50 to 264.30 mg/kg, 16 to 230 mg/kg, 1.5 to 35.60 mg/kg, 0.67 to 14 mg/kg and 0.30 to 3.3 mg/kg, respectively (Table- 4.5). The mean values exhibited the following order: Zn (142.83 mg/kg) > Cu (67.10 mg/kg) > Ni (10.37 mg/kg) > Pb (3.87 mg/kg) > Cd (1.47 mg/kg). And the SD of Zn, Cu, Ni, Pb and Cd was ±85.10, ±60.00, ±9.37, ±3.72 and ±0.96, respectively (Appen.Table- 9).

From the above results, it was found that the highest Zn concentration was found in Lal sak (1684 mg/kg) at Demra- 3 near I I Tubes Mills Ltd., followed by Kalmi sak (710 mg/kg) at Gazipur- 5 near Haq Battery and in Kalmi sak (550 mg/kg) at Gazipur- 6 near Mail Bazar, Nisad Gate and the lowest was found at Ashulia- 1 near Shahriar Fabrics. And, high Zn concentration was found in Lal sak (400 mg/kg) at Demra- 2 near Jahir Steel Mills Ltd., in Lal sak (390 mg/kg) at Keranigonj- 4, in Spinach (389.50 mg/kg) at Matuail- 1near Ashmat Ali Steel Mills Ltd., in Spinach (351.80 mg/kg) at Tejgaon- 2 within industrial area, in Kalmi sak (277 mg/kg) at Hazaribagh- 4 within tannery area, in Kalmi sak (481.30 mg/kg) at Matuail- 2 near dyeing industry and in Lal sak (268.30 mg/kg) at Tejgaon- 3 within industrial area and in Grass (264.30 mg/kg) at Tejgaon- 1 within industrial area. And the SD ranged from ±29.10 in Grass and ±660.92 in Lal sak.

The highest Cu concentration was found in Grasses (230 mg/kg) at Demra- 4 near Alaksa Steel and Rerolling Mills Ltd. and the lowest was found at Tejgaon- 2 inside industrial area. High Cu was found in Grass (77 mg/kg) at Matuail- 3 near Dastagir Steel Mills Ltd., in Kalmi sak (77 mg/kg) at Shampur- 1 near Samia Steel Mills Ltd., in Grass (98.10 mg/kg) at Shampur- 2 near dyeing industry, in Grass (74 mg/kg) at Gazipur- 3; BISIC area, in Grass (67

mg/kg) at Hazaribagh- 3 tannery area, in Lal sak (59.40 mg/kg) at Tejgaon-3, in Lal sak (61 mg/kg) at Demra-3 and in Grass (52 mg/kg) at Gazipur- 1. And the SD ranged from ±15.13 of Rice to ±60.0 of Grass (Table- 4.5 and Appen.Table- 9).

The highest Ni concentration was found in Grass (35.60 mg/kg) at Gazipur- 4 near Metrocem Ispat Mills Ltd., followed by Lal sak (30.70 mg/kg) at Demra- 3 near I I Tubes and Pipe Mills Ltd. and the lowest was found at Demra- 4 near Alaksa Steel Mills. Higher amounts of Ni was found in Rice (14.69 mg/kg) at Savar- 3 near Fazlul Haq Steel Mills Ltd., in Kalmi sak (14.20 mg/kg) at Shampur- 1 near steel industry, in Grass (14 mg/kg) at Shampur- 2 near dyeing industry, in Grass (16.10 mg/kg) at Hazaribagh- 3 within tannery industrial area, in Kalmi sak (17.90 mg/kg) at Gazipur- 5 near Haq Battery and in Kalmi sak (15.50 mg/kg) at Gazipur- 6 near Mail Bazar; Nisad Gate. And the SD ranged from ±5.19 of Spinach to ±18.96 of Grasses (Table- 4.5 and Appen.Table- 9).

The highest Pb concentration was found in Kalmi sak (54 mg/kg) at Shampur- 1 near Samia Steel Mills Ltd., followed by Kalmi sak (21 mg/kg) at Shampur-3 near Kadamtali Steel and Rerolling Mills and the lowest was found at Gazipur- 1 at Konabari industrial area. Remarkably higher amount of Pb was also found in Kalmi sak (14 mg/kg) at Hazaribagh- 2, in Grass (14 mg/kg) at Shampur- 2 near dyeing industry and in Lal sak (12 mg/kg) at Demra-2 near Jahir Steel and Rerolling Mills Ltd. And the SD ranged from ±0.54 of Rice to ±14.51 of Kalmi sak (Table- 4.5 and Appen.Table- 9).

The highest Cd concentration was found in Kalmi sak (4.20 mg/kg) at Hotapara- 1, followed by Kalmi sak (4 mg/kg) at Shampur-1 near Samia Steel Mills Ltd, Spinach (3.90 mg/kg) at Hotapara- 3 near Givensee Groups and Kalmi sak (3.90 mg/kg) at Matuail- 2 near dyeing and the lowest was found in Grass at Demra- 4. And, high Cd was found in Rice (3.70 mg/kg) at Hotapara- 2 near Givensee Groups, in Spinach (3.70 mg/kg) at Matuail-1 near metal industry, in Grass (3.30 mg/kg) at Shampur- 2 near dyeing industry, in Grass (3.10 mg/kg) at Hazaribagh- 1 near tannery factory, in Kalmi sak (3.10 mg/kg) at Hazaribagh- 4 near Tannery industry and in Lal sak (2.73 mg/kg) at Demra- 1. And the SD ranged from ±0.37 of rice to ±1.07 of Kalmi sak (Table- 4.5 and Appen.Table- 9).

Metal concentrations in different vegetables and crop plants also varied among different species and the varieties of the same cultivar. Rauf *et al*. (2012) reported that heavy metals in sludge and soil are generally present in a variety of forms exhibiting different degrees of bioavailability and mobility. On the other hand, a wide variation in the concentration of Zn, Cu, Ni, Pb and Cd was found at different locations of the sampling sites. Sauerbeck (1982) reported that the transfer co-efficient of different metals were different. Alegria *et at*. (1991) reported that the anthropogenic activities such as agriculture, industry and urban life increase the Pb, Cd and Ni contents of soils and waters and, therefore, had an effect on the metal contents of vegetables. The variation of metal concentration in vegetables and crop plants at different sites might be due to some soil and plant related factors such pH, organic matter

status, texture and complexation with other soil components, presence and concentration of different heavy metals and the antagonistic and synergistic effect among them and also variety and genotype dependence. Similarly, Naser (2011) reported that the heavy metal content by plants can be affected by several factors including metal concentrations in soils, soil pH, cation exchange capacity organic matter content, types and varieties of plants, and plant age. In addition, heavy metal availability can also be directly affected by plant itself (Zhang *et al.*, 1991). On the contrary, Grunhage and Jager (1985) found that the Cd, Pb, Zn and Cu concentration of shoot of *Allium porrum* increased with increasing heavy metal contamination of soil and no visible symptoms of heavy metal toxicity were recognized. And, the antagonistic effect of Pb, Cd, Zn and Cu uptake by plant was attributed to yield depression. Pb significantly reduced the decrease of Ca, Mg and Fe. Likewise, Smith and Brennan (1983) reported a synergistic interaction between Cd and Zn, while Cataldo *et al.* (1983) observed an antagonistic interaction between Cd and Fe, Zn, Cu, Mn. Then again, Zhang *et al.* (2002) showed genotype dependent effects of Cd on Fe, Zn, Cu, Ca and Mg for uptake and translocation in wheat. The interactions among Cd and other metal nutrients such as Fe, Zn, Cu and Mn was studied with some upland crops and found that there was a significant difference among species and varieties (Cataldo *et al.*, 1983; Smith and Brennan, 1983; Zhang *et al.*, 2002; Wu and Zhang., 2002).

Except Grasses and Rice, Zn contents in other vegetables and crops such as Lal sak, Kalmi sak and Spinach were found above phyto-toxic range as described by Sauerbeck (1982) and the highest mean concentration was found in Lal sak. But, Zn status in all the crops and plants of the surveyed areas was found above the normal concentrations as described by Sauerbeck (1982). Zn concentration in different vegetables and crops exhibited the following descending order: Lal sak> Kalmi sak> Spinach> Grasses> Rice. Copper concentration in Kalmi sak, Grasses, Spinach, Rice and Lal sak was found above the phyto-toxic limit and normal concentration as described by Sauerbeck (1982). The highest Cu concentration was found in Grasses, followed by Lal sak, Rice and Kalmi sak and the lowest was found in Spinach. Nickel concentration in Kalmi sak, Grasses, Spinach and Rice and Lal sak was found below phyto-toxic limit but above the normal concentration as given by Sauerbeck (1982). But, Pb and Cd concentrations in Kalmi sak, Grasses, Spinach and Rice and Lal sak were found below the phyto-toxic limit but above normal and tolerable limit as described by Sauerbeck (1982). Pais and Jones (2000) reported that Zn content in plants ranged from: 10-100 mg/kg (critical value 15 mg/kg) and reference plant 50 mg/kg; Cu content in plants ranged from: 1-10 mg/kg, reference plant 10 mg/kg; Ni content in plants such as pasture ranged from: 0.3-3.5 mg/kg, reference plant 1.5 mg/kg; Pb content in plants: reference plant 1.0 mg/kg, background level in grasses is 2.1 mg/kg and 2.5 mg/kg in clover and leafy vegetables such as lettuce has a high bioaccumulation character for Pb; Cd contents in plants ranged from: 0.1-1.0 mg/kg, reference plant 0.05 mg/kg. On the other hand, 3 mg/kg Cd will reduce growth. According to FAO/WHO (2001), the limit values of heavy metals such as Zn,

Cu, Ni, Pb and Cd in vegetable crops is 50 mg/kg, 10 mg/kg, 0.02-2.70 mg/kg, 0.30 mg/kg and 0.20 mg/kg respectively.

And it is evident from the above results that the collected plant samples were found highly contaminated by Zn, Cu, Pb and Cd and in most cases exceeded the phyto-toxic limit except Ni. Ullah *et al*. (1999), Davies *et al*. (1979) and Hibben *et al*. (1984) observed that Indian spinach had a tendency to take up large amount of Pb grown on by roadsides and industrial sites. Hossain *et al*. (2007) studied on the transfer of Cd from soil to the vegetable crops and found that the transfer factor of Cd in roots of vegetables decreased in the order: Lettuce> Spinach> Data sak > Lal sak; in shoots the order of Cd concentration was: Data sak > Spinach > Lettuce > Lal sak and the transfer factor varies from 2.03 to 6.785 in roots and 0.166 to 0.525 in shoots. Several studies showed that the uptake of the metals by vegetable plants increased with increasing concentration of heavy metals in soil (Davis *et al*., 1979). Conversely, some species of grasses are Pb tolerant, some has been found to contain high levels of Pb in soil (RCEP, 1983). Similarly, Rotikittkhun *et al*. (2007) identified some species of grasses that could tolerate high Pb concentrations in soils and showed a very good growth performance. In contrast, Tyksinski *et al*. (1993) found excessive concentration of Pb, Cd and Cu in leafy vegetables, rooty vegetables and other vegetable crops grown on contaminated soils. This study corroborate with the findings of Guttormsen *et al*. (1995) and Dowdy and Larsen (1995). They reported that vegetables and plants grown in heavy metal contaminated soils had higher concentration of heavy metals than those grown in uncontaminated soils. Kashem and Singh (1998) reported that the concentration of the most heavy metals (Zn, Cu, Ni, Pb, Cd) were higher in vegetation samples of tannery areas and the content of Pb (13 - 45 mg/kg) in grass samples exceeded the toxic limit. Likewise, Naser *et al*. (2009) investigated some vegetables from industrially polluted soils around Dhaka and found that Pb, Cd, and Ni concentrations in the studied vegetables were higher than those in vegetables from other countries. Nuruzzaman (1995) found excessive concentrations of several heavy metals in the plants adjacent to pharmaceuticals, battery industry (Tongi) and tannery factories (Hazaribagh) around Dhaka.

4.2 Green House Study: Effect of Heavy Metals on Crops and Their Phyto-Remediation

In the green house study, relative performances of different rice cultivars, vegetables and other crops and their growth and yield parameters such as raw weight, dry weight of straw and grain yield/pot and mineral nutrition, under various treatment levels of different heavy metals were investigated. The test of significance of the treatment means were calculated by Duncan's New Multiple Range Test (DMRT) and paired samples T- test.

4.2.1 Growth, Yield, Mineral Nutrition and Pb Contents in Brridhan- 28 Rice as Affected by Different Levels of Pb (Experiment- 1a)

Growth can be defined as a permanent change in volume which is usually accompanied by change in form (Thomas and Richardson, 1960). According to Mayer and Anderson (1962), the increase in the length of stem and root or other organ of the plant, increase in the area of the leaves, and increase in dry and fresh weight of plant is known as growth. The growth and yield of plants are normally enhanced by essential nutrient elements. But, excessive amounts of some essential elements may also be toxic to both plants and animals.

4.2.1.1 *Fresh weight, dry weight and grain yield*

The growth and physical appearance of 60 days old Brridhan- 28 rice as affected by Pb different levels of Pb treatments have been depicted in Plate- 13 and the results pertaining to the effect of different concentrations of Pb on fresh biomass yield, dry matter yield and grain yield of Brridhan- 28 rice variety have been presented in Table- 4.6. The effect of Pb on the fresh weight, dry weight and grain weight of the rice varieties per pot (g) was found significant at 1% level. The test of significance of different treatment means was computed by Duncan's New Multiple Range Test (DMRT) at 5% level.

Plate- 13: The growth and physical appearance of Brridhan- 28 rice as affected by Pb treatments

The fresh weight of the straw of Brridhan- 28 rice ranged from 109.00 to 145.33 g/pot. The maximum fresh weight was obtained at control (T0) and the minimum was obtained at T8 treatment, where 350 mg/kg Pb was applied. The fresh weight at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments were 145.33, 143.67, 140.67, 138.00, 135.67, 127.67, 119.33, 114.00 and 109.00 g/pot, respectively.

Table- 4.6: Fresh weight, dry weight and grain yields (g/ pot) of Brridhan- 28 rice variety as affected by Pb-toxicity

Treatment denotations	Applied Pb (mg/kg)	Yield Parameters		
		Fresh weight (g/pot)	Dry weight (g/pot)	Grain weight (g/pot)
T0	Control	145.33 a	30.05 a	44.91 a
T1	100	143.67 ab	29.69 ab	43.20 ab
T2	125	140.67 bc	29.08 abc	41.70 bc
T3	150	138.00 cd	28.48 c	40.47 cd
T4	175	135.67 d	28.05 d	38.63 de
T5	200	127.67 e	26.40 e	33.85 f
T6	250	119.33 f	24.54 f	29.84 g
T7	300	114.00 g	23.92 g	26.37 h
T8	350	109.00 h	21.96 h	21.47 i

Mean values in the same column with the same letter(s) are not significantly different (p=0.05)

The declining trend of fresh weight was initiated at T1 treatment, where 100 mg/kg Pb was applied over control. In fact, control (T0), T1, T2, T3 and T4 treatments were found statistically similar, but control (T0) and T2, T1 and T3 and T2 and T4 treatments were found significantly different from each other. On the other hand, treatments T5, T6, T7 and T8 were found significantly different from each other and also from T0 (control), T1, T2, T3 and T4 treatments. However, a decreasing trend of fresh weight reduction was observed with an increasing Pb application. Then again, due to Pb treatment, the percent reduction of fresh weight was observed over control, which ranged from 1.10 to 24.99 % (Figure- 4.1).
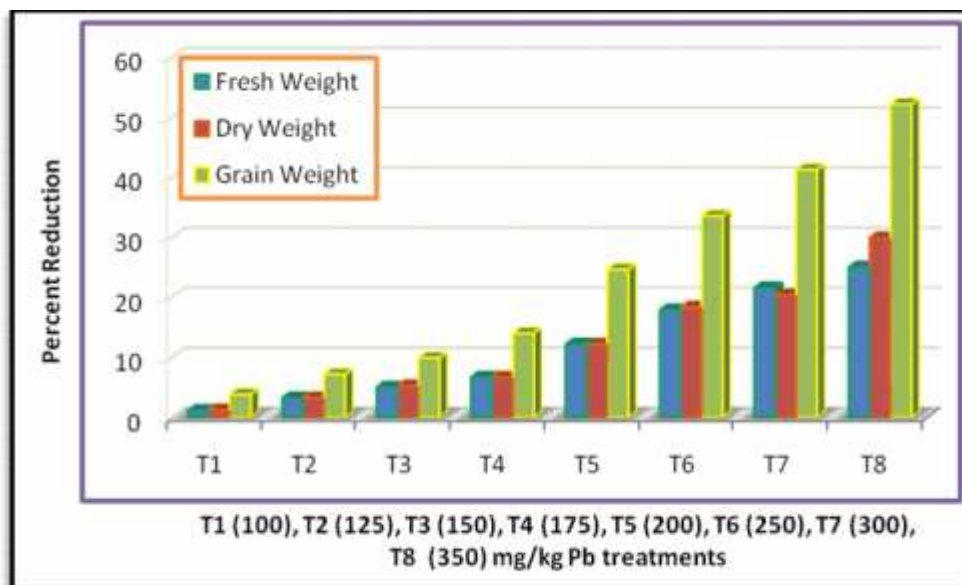
Figure- 4.1: Percent reduction of fresh weight, dry weight and grain yield of Brridhan - 28 rice as affected by various treatments of Pb over control

The dry weight of Brridhan- 28 rice straw ranged from 21.96 to 30.05 g/pot. The values were 30.05, 29.69, 29.08, 28.48, 28.05, 26.40, 24.54, 23.92 and 21.96 at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments, accordingly. The decreasing trend of dry matter production

of Brridhan- 28 rice was initiated at T1 (100 mg/kg Pb) treatment and continued up to T8, where 350 mg/kg Pb was applied. Actually, no significant difference was found among control (T0), T1, T2 and T3 treatments, but control (T0) and T3 and T1 and T3 treatments were significantly different from each other. On the other hand, treatments T4, T5, T6, T7 and T8 were significantly different from each other and also from control (T0), T1, T2, T3 and T4 treatments. The highest dry matter yield was obtained at control and the lowest amount of dry matter yield was obtained at T8 treatment, where maximum amount of Pb was applied. Then again, it was obvious that the dry weight was decreased with increasing Pb application over control. Like fresh weight, the dry weight of Brridhan- 28 rice was declined by 1.20 to 29.92 % over control (Fig- 4.1).

The grain yield of Brridhan- 28 rice ranged from 21.47 to 44.91 g/pot (Table- 4.6). The grain weight at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments were 44.91, 43.20, 41.70, 40.47, 38.63, 33.85, 29.84, 26.37 and 21.47 g/pot, respectively. The maximum yield was obtained at T0 (control) and the minimum was obtained at T8 treatment, where 350 mg/kg Pb was applied. A decreasing trend of grain yield was observed with increasing Pb concentration. As a matter of fact, T0 (control), T1, T2, T3 and T4 treatments were found statistically similar. And, control (T0) and T2, T1 and T3 and T2 and T4 treatments were significantly different from each other. On the other hand, treatments T5, T6, T7 and T8 were found significantly different from each other and also from T0 (control), T1, T2, T3 and T4 treatments. When compared with control, the grain yield of rice had been reduced by 3.80 to 52.19% with increasing Pb treatments (Fig- 4.1).

The results of the present investigation were in agreement with the findings of John *et al.* (2008) and Ullah *et al.* (2011). Likewise, Patrick and Bisessar (1991) also found the severe reduction of fresh weight of *Lemna polyrrhiza* by Pb toxicity. The reduced fresh weight of rice grain with increasing Pb toxicity was also reported by Lubis (1988) and Lee and Kim (1991). The most common effect of Pb is on the chlorophyll and protein synthesis in plants which ultimately affect the fresh weight and dry matter yield of plants and various biotic stresses decrease the chlorophyll content in plants (Ahmed *et al.*, 2007). Several authors reported that chlorophyll biosynthesis was inhibited by metals in higher plants (Prasad and Prasad, 1987). On the other hand, Sharma and Dubey (2005) found that the length as well as weight of shoots and roots of rice (*Oryza sativa*) decreased with increased Pb concentration.

John *et al.* (2008) and Lee and Kim (1991) revealed that the decrease in dry matter yield of rice straw was due to increased Pb application. Similarly, Kosobrukhov *et al.* (2004) also observed a considerable decrease in dry weights of plant parts under Pb treatment. Likewise, Patrick and Bisessar (1991) observed that the weight of fresh and dry matter of onion, potato, cabbage and lettuce were reduced severely by Pb toxicity. And, Strand *et al.* (1990) also observed Pb toxicity to plants affected the dry matter yield of rice. Moreover, Kibria *et al.* (2006) and Ullah *et al.* (2011) obtained the lowest dry weight of grain, shoot and roots at the

highest Pb treatment. On the other hand, Kim *et al*. (1986) and Santo-Diaz and Cirageda-Delgado (1992) observed that the dry weight of rice reduced with increasing Pb toxicity. In the case of grain yield, several researchers (Wolnik *et al*., 1983; Hibben *et al*., 1984; Moser, 1986; Sameni *et al*., 1987; Juma and Tabatabai, 1988; Ullah and Gerzabek, 1991; Patel *et al*., 1996) reported that metal reduced the yield of crops. Chattarjee *et al*. (2006) also revealed that excess Pb reduced both the dry weight and grain yield of rice.

4.2.1.2 *Nitrogen contents in grains, straw and roots*

The mean values of N contents in the grains, straw and roots of Brridhan- 28 rice as affected by different levels of Pb treatments are presented in Appen.Table- 10 and Figure- 4.2. The results were statistically significant at 1% level and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

The mean N concentrations in the grains of Brridhan- 28 rice as affected by applied Pb ranged from 1.30 to 1.88%. The corresponding values were 1.87, 1.86, 1.84, 1.83, 1.81, 1.59, 1.40 and 1.30%, respectively at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments. The highest content was found at T0 (control) and the lowest was found at T8 treatment, where 350 mg/kg Pb was applied. With increasing Pb treatments, the reduction in N concentration was found at T1 treatment, where 100 mg/kg Pb was applied and continued up to T8 (350 mg/kg Pb) treatment. In fact, T0 (control) and T1 and T2, T3 and T4 treatments were found statistically similar, but treatment T2 was significantly different from T4.
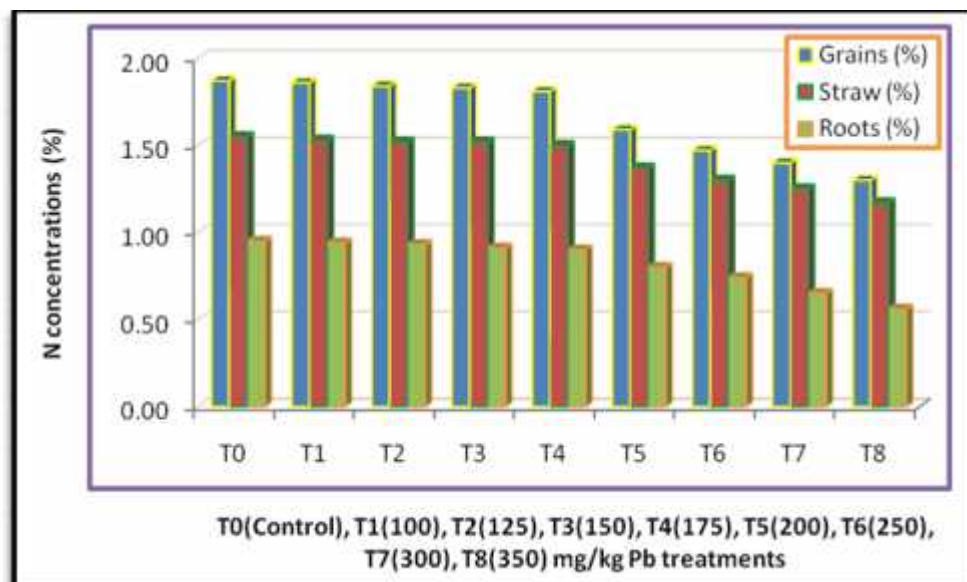
Figure- 4.2: Nitrogen concentrations in grains, straw and roots of Brridhan-28 rice as affected by various treatments of Pb

On the contrary, treatments T5, T6, T7 and T8 were significantly different from each other and also from T0 (control), T1, T2, T3 and T4 treatments.

Nitrogen contents in the straw of Brridhan- 28 rice ranged from 1.17 to 1.55 % as affected by different levels of Pb. N contents in the straw of rice at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments were 1.55, 1.53, 1.52, 1.52, 1.50, 1.37, 1.30, 1.25 and 1.17%, respectively. The highest concentration was found at T0 (control) and the reduction of N concentration was initiated at T1 (100 mg/kg Pb) and continued up to T8 treatment, where 350 mg/kg Pb was applied. As a matter of fact, N concentration at T0 (control), T1, T2, T3 and T4 treatments were found statistically similar. In contrast, T0 (control) and T2, T3 and T4 and T2 and T4 treatments were found significantly different. On the other hand, treatments T5, T6, T7 and T8 were also found significantly different from each other and also from T0 (control), T1, T2, T3 and T4.

As affected by different levels of applied Pb, the mean values of N concentrations in the roots of Brridhan- 28 rice ranged from 0.56 to 0.95%. The related values at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments were 0.95, 0.94, 0.93, 0.91, 0.90, 0.80, 0.74, 0.65 and 0.56%, respectively. The highest concentration was obtained at control. The increasing Pb treatments resulted the decrement of N contents which was initiated at T1 (100 mg/kg Pb) and prolonged up to T8 treatment (350 mg/kg Pb), where the lowest content was found. But, N concentrations at T0 (control), T1 and T2 were found statistically similar, but T2 treatment was found significantly different from T0 (control). Similarly, treatments T3, T4, T5, T6, T7 and T8 were found significantly different from each other and also from T0 (control), T1 and T2 treatments.

From the above results, it was found that N content in grains, straw and roots of rice decreased with increasing treatment levels of Pb. The results were in accordance with the findings of Strand *et al*. (1990) and Ullah *et al*. (2011). An antagonistic effect of Pb on N uptake by rice plants was observed by Lee and Kim (1991). On the other hand, Sharma and Dubey (2005) reported that Pb blocked the entry of NO_3^- in the root systems in most cases.

4.2.1.3 *Phosphorus contents in grains, straw and roots*

The mean values of P in the grains, straw and roots of Brridhan- 28 rice as affected by different levels of Pb treatments have been presented in Appen.Table- 10 and Figure- 4.3. The results were statistically significant at 1% level and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

Phosphorus content in the grains of Brridhan- 28 rice was affected by Pb treatments. The contents in grains of rice ranged from 0.23 to 0.50%. The subsequent values of P at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments were 0.50, 0.48, 0.45, 0.43, 0.40, 0.36, 0.32, 0.25 and 0.23%, respectively. The highest concentration was found at T0 (control) and the lowest was obtained at T8 treatment, where 350 mg/kg Pb was applied. On the other hand, a significant reduction was obtained at T1 treatment, where 100 mg/kg Pb was applied and continued up to T8 (350 mg/kg Pb) treatment. But, P concentrations at all the treatments levels were found significantly different from each other.

Phosphorus content in the straw of rice ranged from 0.20 to 0.41%. The contents in the straw were 0.41, 0.40, 0.39, 0.38, 0.37, 0.29, 0.24, 0.21 and 0.20%, respectively at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments. The highest was found at T0 (control) and the decreasing trend was initiated at T1 treatment, where 100 mg/kg Pb was applied. And, the lowest concentration was found at T8 treatment, where 350 mg/kg Pb was applied. As a matter of fact, P concentrations at T0 (control), T1, T2 and T3 treatments were found statistically similar. Conversely, T0 (control) was found significantly different from T2 and T3 treatments. Similarly, T1 and T3 treatments were also significantly different from each other. On the other hand, treatments T4, T5, T6, T7 and T8 were significantly different from each other and also from T0 (control), T1, T2 and T3 treatments.

Figure- 4.3: Phosphorus concentrations in grains, straw and roots of Brridhan- 28 rice as affected by different treatments of Pb

Phosphorus contents in the roots of Brridhan- 28 rice ranged from 0.08 to 0.23%. The contents in the roots at treatments T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 were 0.23, 0.22, 0.21, 0.19, 0.18, 0.15, 0.12, 0.10 and 0.08%, respectively. The highest concentration was found at control, but the decreasing trend was initiated at T1 treatment, where 100 mg/kg Pb was applied, and it was continued up to T8 treatment, where 350 mg/kg Pb was applied. And, the lowest concentration was obtained at T8 treatment, where the highest amount of Pb was applied. In fact, P content at T0 (control), T1 and T2 and T3 and T4 treatments were found statistically similar, but T0 (control) and T2 treatments were significantly different from each other. On the other hand, treatments T5, T6, T7 and T8 were significantly different from each other and also from T0 (control), T1, T2, T3 and T4 treatments.

The results were in accordance with the finding of Ullah *et al.* (2011) and Muchrimsyah and Mercado (1990). They found that the P concentration was decreased in straw and grains of rice with increased Pb treatments. On the other hand, Paivoke (2002) reported that Pb

influenced the overall distribution of nutrient elements within different organs of plants. According to Adriano (1986), the presence of more amounts of Pb in soils reacts with phosphate and forms $Pb_3 (PO_4)_2$ and then precipitate and ultimately reduce P accumulation by plants.

4.2.1.4 *Potassium concentrations in grains, straw and roots*

The mean values of K concentration in the grains, straw and roots of Brridhan- 28 rice as affected by different levels of Pb treatments are presented in Appen.Table- 10 and Figure- 4.4. The results were statistically significant at 1% level. The test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

Potassium is an essential plant nutrient. But, due to augmented application of Pb in soils, K concentrations in the grains, straw and roots were decreased significantly. The mean K contents in the grains ranged from 2.00 to 2.53%. The values were 2.53, 2.50, 2.48, 2.46, 2.45, 2.32, 2.22, 2.15 and 2.00%, respectively at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments. The highest contents were found at T0 (control) and with successively increased Pb application, a reducing trend was observed at T1 treatment. As a matter of fact, K concentrations at T0 (control), T1, T2, T3 and T4 treatments were found statistically similar. On the other hand, T0 (control) was found significantly different from T2, T3 and T4 treatments, and T4 treatment was also significantly different from T0 (control), T1 and T2 treatments.
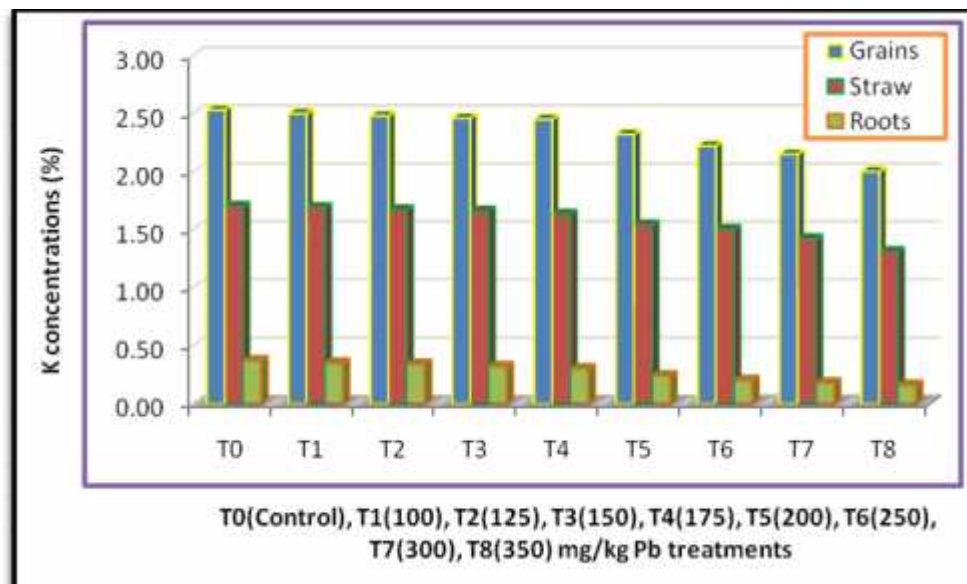
Figure- 4.4: K concentrations in grains, straw and roots of Brridhan-28 rice as affected by different treatments of Pb

And, the significant reduction of K concentration was recorded at T5 treatment and onwards. Therefore, treatments T5, T6, T7 and T8 were significantly different from each other and also from T0 (control), T1, T2, T3, T4 treatments.

The mean K concentration in the straw of Brridhan- 28 rice ranged from 1.31 to 1.70%. The corresponding values were 1.70, 1.69, 1.67, 1.66, 1.63, 1.54, 1.50, 1.42 and 1.31%, respectively at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments. The highest content was found at T0 (control), but with subsequently increased Pb application, K concentration in the rice straw was decreased. And, as a result, the lowest was recorded at T8 treatment, where the highest amount (350 mg/kg) of Pb was applied. In the straw of rice, K concentration at T0 (control), T1, T2, T3 and T4 treatments were found statistically similar. On the contrary, T0 (control) was significantly different from T2, T3 and T4 treatments, whereas treatments T2 and T4 were also found significantly different from each other. Conversely, treatments T5, T6, T7 and T8 were significantly different from each other and also from T0 (control), T1, T2, T3 and T4 treatments.

Potassium concentration in the roots of Birridhan- 28 rice ranged from 0.16 to 0.37 %. And, the subsequent K concentrations at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments were 0.37, 0.35, 0.34, 0.32, 0.30, 0.24, 0.20, 0.18 and 0.16%, respectively. Like grains and straw, the highest content was found at T0 (control). The significant reduction of K concentration was found at T1 treatment, where 100 mg/kg Pb was applied over control and the lowest content was found at T8 treatments, where 350 mg/kg Pb was applied. On the other hand, T1 and T2 and T3 and T4 treatments were found statistically similar. But, treatments T5, T6, T7 and T8 were found significantly different from each other and also from T0 (control), T1, T2, T3 and T4 treatments. A decreasing trend of K concentration was found in the grains, straw and roots of Brridhan- 28 rice with increasing Pb treatments.

Similar results were noticed by Ullah *et al*. (2011). They reported that K concentration was decreased in the straw and grains of rice due to the increased Pb application. Accordingly, several researchers (Khan and Khan, 1983; and Kim *et al*., 1986; Trivedi and Erdei, 1992) reported that the increasing Pb concentration had an adverse impact on K uptake by rice plant and Pb reduced the uptake of K^+ significantly in roots and grains. In addition, Sharma and Dubey (2005) found an antagonistic effect between K^+ and Pb uptake by rice plants.

4.2.1.5 *Calcium concentrations in grains, straw and roots*

The mean values of Ca concentration in the grains, straw and roots of Birridhan- 28 rice as affected by different levels of Pb treatments are presented in Appen.Table- 11 and Figure- 4.5. The results were statistically significant at 1% level and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5 % level.
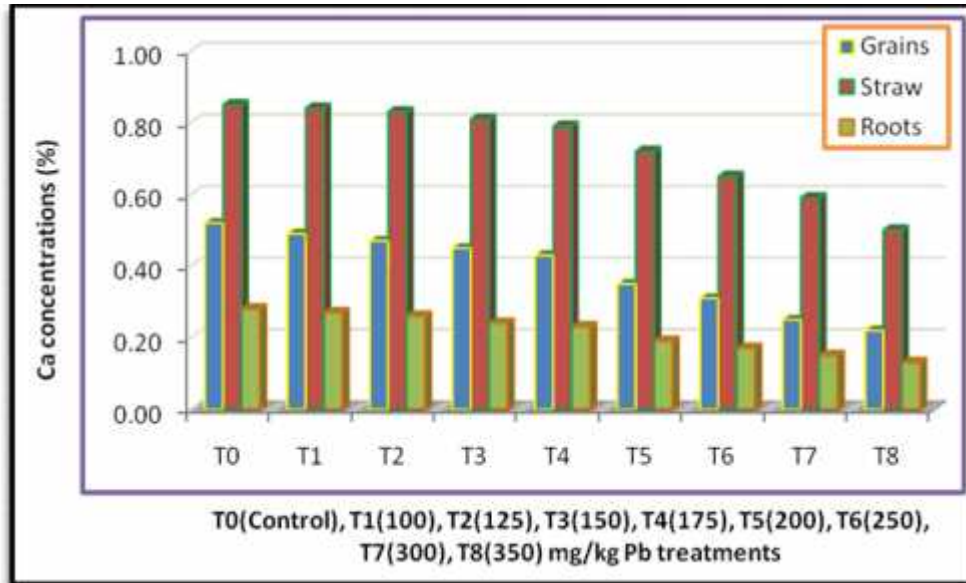
Figure- 4.5: Ca concentrations in grains, straw and roots of Brridhan - 28 rice as affected by various treatments of Pb

Ca contents in rice grains, straw and roots were negatively influenced by Pb treatments. The Ca contents in the grains of Brridhan- 28 rice ranged from 0.22 to 0.52 %. The corresponding values were 0.52, 0.49, 0.47, 0.45, 0.43, 0.35, 0.31, 0.25 and 0.22%, respectively at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments. The highest concentration was found at T0 (control) and the lowest was found at T8 treatment, where 350 mg/kg Pb was applied. A significant reduction of Ca concentration was initiated at T1 treatment, where 100 mg/kg Pb was applied over control. In fact, Ca contents at treatments T0 (control), T1, T4, T5, T6, T7 and T8 were found significantly different from each other, whereas treatments T2 and T3 were found statistically similar.

Calcium contents in the straw of rice ranged from 0.50 to 0.85%. The concentrations at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments were 0.85, 0.84, 0.83, 0.81, 0.79, 0.72, 0.65, 0.59 and 0.50%, respectively. The highest was found at T0 (control) and the lowest was obtained at T8 treatment, where the highest amount (350 mg/kg) of Pb was applied. Ca contents at T0 (control), T1 and T2 treatments were found statistically similar. Conversely, control (T0) and T2 were found significantly different from each other. On the other hand, treatments T3, T4, T5, T6, T7 and T8 were significantly different from each other and also from T0 (control), T1 and T2.

Like grains and straw, Ca content in the roots of Brridhan- 28 rice ranged from 0.13 to 0.28%. At T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments, the corresponding Ca contents were 0.28, 0.27, 0.26, 0.24, 0.23, 0.19, 0.17, 0.15 and 0.13%, respectively. The highest concentration was found at T0 (control) and the lowest was obtained at T8 treatment, where the highest amount of Pb was applied. As a matter of fact, a significant reduction of Ca content was initiated at T1, where 100 mg/kg Pb was applied over control. But, T0 (control)

and treatments T1, T2, T3, T4, T5, T6, T7 and T8 were found significantly different from each other.

It was evident from the above results that the successive and increasing application of Pb suppressed the contents of Ca in grains, straw and roots of Brridhan- 28 rice, but the reduction was more pronounced at the higher levels of Pb treatments. Similar results were also reported by many authors (Kim *et al*., 1986; Xian, 1989; Trivedi and Erdei, 1992; Warter, 1992). On the other hand, Lee and Kim (1991) observed an antagonistic effect on Ca uptake by rice plants due to Pb toxicity. Likewise, Ullah *et al*. (2011) reported that Ca contents in the rice straw and grain decreased with increased levels of Pb significantly. According to Sharma and Dubey (2005), Pb restricted the entry of Ca^{2+} into the root system of rice plants and reduced their uptake.

4.2.1.6 *Magnesium contents in grains, straw and roots*

The mean values of Mg content in the grains, straw and roots of Brridhan- 28 rice as affected by different levels of Pb treatments have been presented in Appen.Table- 11 and Figure- 4.6. The results were statistically significant at 1% level and the test of significance of different treatment means was computed by DMRT at 5% level.

The mean Mg contents in grains of Brridhan- 28 rice varied from 0.37 to 0.76%. The subsequent contents at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments were 0.76, 0.65, 0.63, 0.57, 0.55, 0.50, 0.46, 0.41 and 0.37%, respectively. The highest content was observed at T0 (control) and the lowest was obtained at T8 treatment, where 350 mg/kg Pb was applied. However, Mg content in grains at T0 (control) and treatment T1 and T2 and T3 were found statistically similar. On the other hand, treatments T4, T5, T6, T7 and T8 were found significantly different from each other and also from T0 (control), T1, T2, T3 treatments.

Like grains, the mean Mg contents in the straw of rice varied from 0.36 to 0.70%. The contents at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments were 0.70, 0.70, 0.68, 0.67, 0.66, 0.53, 0.47, 0.40 and 0.36%, respectively. The highest was observed at T0 (control) and the lowest was obtained at T8, where 350 mg/kg i.e., the highest amount of Pb was applied. A declining trend of Mg concentration was commenced with increasing Pb treatments. As a matter of fact, control (T0), T1 and T2 treatments were found statistically similar. Oppositely, control (T0) and T2 treatments were significantly different from each other. On the other hand, treatments T3, T4, T5, T6, T7 and T8 were significantly different from each other treatments and also from T1, T2 and control (T0).
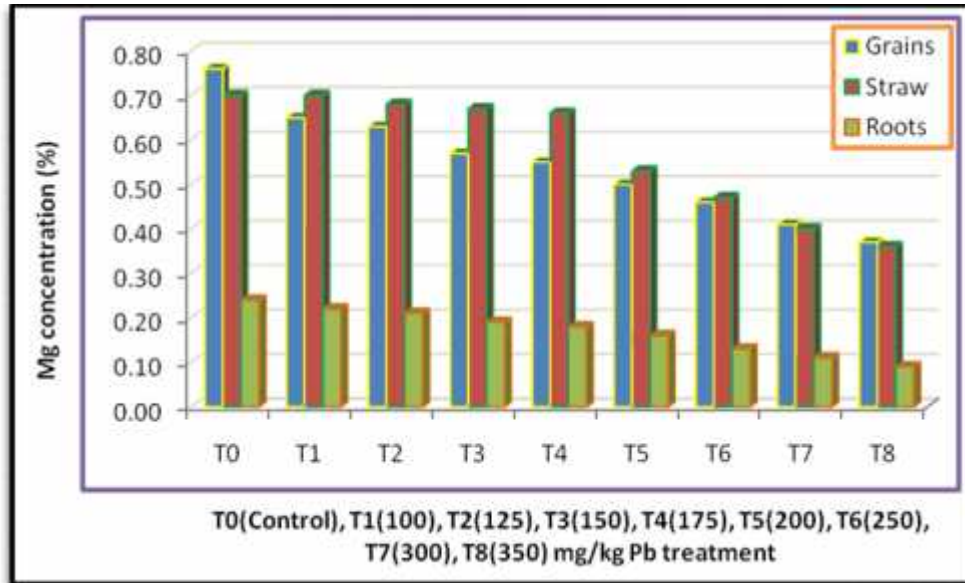
Figure- 4.6: Mg concentrations in grains, straw and roots of Brridhan-28 rice as affected by different treatments of Pb

Mg contents in the roots of Brridhan- 28 rice varied from 0.09 to 0.24%. The values were 0.24, 0.22, 0.21, 0.19, 0.18, 0.16, 0.13, 0.11 and 0.09%, respectively at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments. The highest content was observed at control (T0) and the lowest was recorded at T8 treatment. A significant reduction of Mg concentration was observed at T1 treatment over control, where 100 mg/kg Pb was applied. In fact, Mg contents at treatments T1 and T2 and T3 and T4 were found statistically similar. On the other hand, treatments T5, T6, T7 and T8 were significantly different from each other and from control (T0) and T1, T2, T3 and T4 treatments.

From the above discussion, it could be concluded that the increased Pb treatments gradually decreased Mg contents in the grains, straw and roots of Brridhan- 28 rice over control. Conversely, the Mg accumulation by rice plants was adversely affected by Pb toxicity. The findings were in consonance with the earlier reports of several authors (Xian, 1989; Walker *et al.*, 1997; Ullah *et al.*, 2011). They also observed that the Mg concentration in grains and straw of rice was decreased with increasing Pb treatments. Similar results were also found by Kim *et al.* (1986) and Sharma and Dubey, (2005). Hirayama and Kobayashi (1989) and Lee and Kim (1991) further added that the Mg uptake by rice plants was adversely affected by Pb toxicity.

4.2.1.7 *Pb contents in grains, straw and roots*

The mean values of Pb concentration in grains, straw and roots of Brridhan- 28 rice as affected by different levels of Pb treatments are presented in Table- 4.7. The results were found highly significant (1% level) and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

The Pb contents in the grains, straw and roots of Brridhan- 28 rice ranged from 0.0 (zero) to 4.03 mg/kg, 2.63 to 40.88 mg/kg and 7.23 to 503.33 mg/kg, respectively. In grains the corresponding values were 0.00, 0.25, 0.36, 0.48, 0.65, 0.98, 1.35, 2.96 and 4.03 mg/kg, respectively at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments. On the other hand, in straw, the values were 2.63, 6.30, 7.75, 9.05, 11.79, 15.40, 18.30, 28.92 and 40.88 mg/kg, accordingly at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments. In roots, the order was 7.33, 116.67, 131.67, 150.38, 252.33, 272.33, 316.67, 432.33 and 503.33 mg/kg, respectively at T0 (control), T1, T2, T3, T4, T5, T6, T7 and T8 treatments. The highest concentration was found at T8, where the maximum amount of Pb was applied and the lowest was found at control (T0). On the other hand, an increasing trend of Pb content was observed with increasing Pb application over control (Figure- 4.7), while a significant increment was exhibited at T1 treatment, where 100 mg/kg Pb was applied. In fact, when compared with control, Pb concentrations in the grains and straw at all the treatments (T1, T2, T3, T4, T5, T6, T7 and T8) were found significantly different from each other and also from control.

Table- 4.7: Concentrations and the transfer co-efficients of Pb in grains, straw and roots of Brridhan-28 rice as affected by Pb application

Treatment denotations	Applied Pb (mg/kg)	Pb Concentrations					
		Grains		Straw		Roots	
		Conc. (mg/kg)	TC	Conc. (mg/kg)	TC	Conc. (mg/kg)	TC
T0	Control	0.00 i C	-	2.63 i B	-	7.23 g A	-
T1	100	0.25 h C	0.0025	6.30 h B	0.063	116.67 f A	1.67
T2	125	0.36 g C	0.0029	7.75 g B	0.082	131.67 ef A	1.05
T3	150	0.48 f C	0.0032	9.05 f B	0.060	150.38 e A	1.00
T4	175	0.65 e C	0.0037	11.79 e B	0.067	252.33 d A	1.44
T5	200	0.98 d C	0.0049	15.40 d B	0.077	272.33 d A	1.36
T6	250	1.35 c C	0.0054	18.30 c B	0.073	316.67 c A	0.87
T7	300	2.96 b C	0.0099	28.92 b B	0.096	432.33 b A	1.44
T8	350	4.03 a C	0.0115	40.88 a B	0.117	503.33 a A	1.44

Mean values with the same letter in the same row (C letters) and the same column (S letters) are not significantly different (p=0.05)

On the other hand, Pb contents in the roots of T1, T2 and T3 and T4 and T5 treatments were found statistically similar, but at the same time T1 was significantly different from T3 treatment. Then again, treatments T6, T7 and T8 were found significantly different from each other as well as from control (T0) and T1, T2, T3, T4 and T5 treatments.
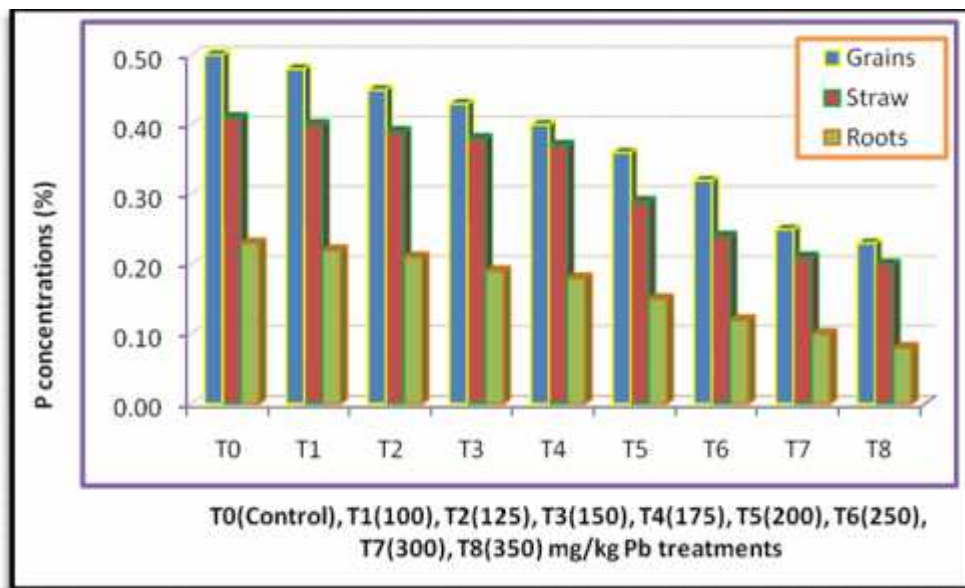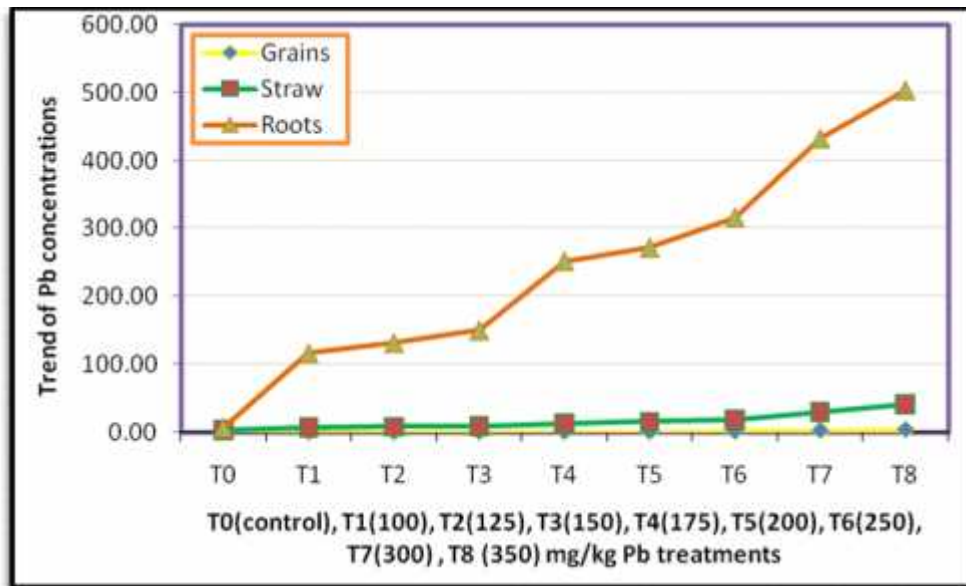
Figure- 4.7: Trend of Pb concentrations in grains, straw and roots of Brridhan- 28 rice as affected by different treatments of Pb

It was also speculated that Pb concentration in the roots of rice was found several times higher than straw and grains. At different treatment levels, the transfer co-efficient of Pb in the grains, straw and roots of rice ranged from 0.0025 to 0.0115, 0.060 to 0.117 and 0.87 to 1.67, respectively (Table- 4.7). However, Pb concentrations in different organs of Brridhan-28 rice decreased in the following descending order: roots > straw > grains.

The results were in accordance with the findings of several researchers (Kim *et al*., 1992; Santo-Diaz and Cirugeda-Delgado 1992; Kibria *et al*., 2006; Ullah *et al*., 2011). They found an increasing trend of Pb concentration in the rice plants with increasing Pb application. On the other hand, Kibria *et al*. (2006) reported that Pb levels in different parts of rice showed the order of descendence: root > shoot > grain. Similarly, Kumar *et al*. (1995) reported that the bulk of the Pb taken up by plants remained in roots. However, Liu *et al*. (2003a) reported that the Pb concentrations decreased rapidly from roots to grain of rice plants. And, it is important to notice that all Pb bearing compounds greatly increase Pb concentrations in the tissues of rice plants (Chen *et al*., 1991).

4.2.2 Growth, Yield, Mineral Nutrition and Cd Contents of Birridhan - 28 Rice as Affected by Different Levels of Cd (Experiment- 1b)

4.2.2.1 *Fresh weight, dry weight and grain yield*

The effects of Cd on the growth and the physical appearance of 60 days old Brridhan- 28 rice as compared to that of control have been depicted in Plate- 14. The mean values of fresh weight, dry weight and grain yield of Brridhan- 28 rice as affected by Cd- toxicity are presented in Table- 4.8. And, the results were found statistically significant at 1% level and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

Plate- 14: The growth and physical appearance of Brridhan- 28 rice as affected by various levels of Cd treatments

The fresh weight of Brridhan- 28 rice varied from 38.36 to 145.33 g/pot. The values were 145.33, 131.30, 120.25, 109.30, 95.67, 55.50 and 38.36 g/pot, respectively at T0 (control), T1, T2, T3, T4, T5 and T6 treatments. The highest fresh weight was obtained at T0 (control) and the lowest was obtained at T6 treatment, where 30 mg/kg Cd was applied. And, a decreasing trend of fresh weight was observed with increasing Cd treatment. However, the fresh weight at control (T0) and T1, T2, T3, T4, T5 and T6 treatments were significantly different from each other. On the other hand, the fresh weight decrement of Brridhan- 28 rice varied from 9.67 to 73.81% over control (Figure- 4.8). And, the highest fresh weight decrement (73.81%) was found at T6 treatment, where 30 mg/kg Cd was applied and at treatments T7 and T8 plant death occurred, where 60 and 90 mg/kg Cd were applied (Plate- 17).

The dry weight of the straw of rice ranged from 8.37 to 30.05 g/pot. The corresponding values were 30.05, 27.30, 24.20, 21.70, 18.50, 11.56 and 8.37 g/pot, respectively at control (T0) and T1, T2, T3, T4, T5 and T6 treatments. The highest dry weight was obtained at control (T0) and the lowest was found at T6 treatment, where 30 mg/kg Cd was applied. No dry matter was obtained at T7 and T8 treatments, because plants were died. As a matter of fact, the dry weight at T1, T2, T3, T4, T5 and T6 treatments were significantly different from each other and also from control (T0). When compared with control, the percent reduction of dry weight varied from 10.15 to 72.19 and the highest reduction was obtained at T6 treatment, where 30 mg/kg Cd was applied (Figure- 4.8).

Table- 4.8: Fresh weight, dry weight and grain yield (g/ pot) of Brridhan- 28 rice variety as affected by Cd-toxicity

Treatment denotations	Applied Cd (mg/kg)	Yield Parameters		
		Fresh weight (g/pot)	Dry weight (g/pot)	Grain weight (g/pot)
T0	Control	145.33 a	30.05 a	44.91 a
T1	3	131.30 b	27.10 b	38.68 b
T2	5	120.25 c	24.20 c	35.13 c
T3	7	109.30 d	21.70 d	28.77 d
T4	9	95.67 e	18.50 e	24.47 e
T5	15	55.50 f	11.56 f	15.02 f
T6	30	38.36 g	8.37 g	10.50 g
T7	60	-	-	-
T8	90	-	-	-

Mean values with the same letter in the same column are not significantly different (p=0.05)
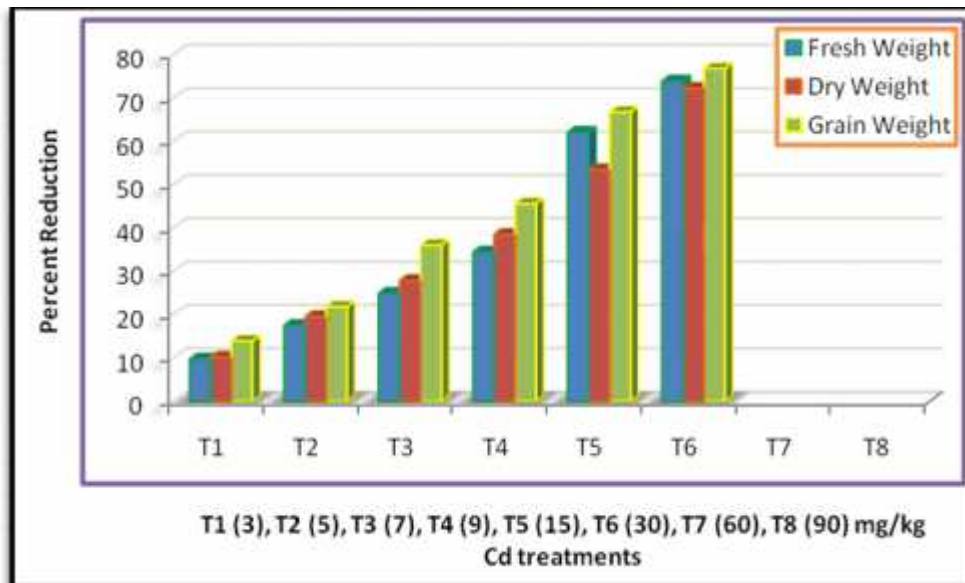
Figure- 4.8: Percent reduction of fresh weight, dry weight and grain yield of Brridhan - 28 rice as affected by various treatments of Cd over control

The grain yield of rice varied from 10.50 to 44.91 g/pot. The values were 44.91, 38.68, 35.13, 28.77, 24.47, 15.02 and 10.50 g/pot, respectively at control (T0) and T1, T2, T3, T4, T5 and T6 treatments. The highest grain yield was obtained at control (T0), but with increasing Cd application, grain yield of rice decreased significantly as compared to that of control (T0). Actually, a significant yield decrement was initiated at T1 treatment, where 3 mg/kg Cd was applied and the trend was continued upwards. On the other hand, the lowest grain yield was obtained at T6 treatment, where 30 mg/kg Pb was applied. When compared with control, the grain weight at T1, T2, T3, T4, T5 and T6 treatments were found significantly different from each other and also from T0 (control). The grain weight decrement varied from 13.89 to

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76.73% (Figure- 4.8) and the highest decline (76.73%) was found at T6 treatment, where 30 mg/kg Cd was applied. However, no grain yield was obtained at T7 and T8 treatments, where plant death occurred.

The deleterious effects on fresh weight, dry matter yield and grain yield was observed significantly and remarkably at T1 treatment, where 3 mg/kg Cd was applied and continued up to T6 treatment, but at T7 and T8 treatments plant death occurred, where 60 and 90 mg/kg Cd were applied. And, it was evident from the results that the fresh weight, dry weight and grain yield of rice were reduced significantly by the application of different levels of Cd. And at higher concentrations, plant death occurred.

Several researchers (Schutzendubel and Polle, 2001; Dhir *et al.*, 2004; Wu *et al.*, 2006; Wahid *et al.*, 2009) reported that Cd toxicity reduced growth, and yield of plants. On the other hand, Wani *et al.* (2007) reported that the excessive amounts of Cd in plant lead to a substantial diminution of total protein. Similarly, Ghani (2010) observed a significant decrement in growth and protein content in *Zea mays*. Padmaja *et al.* (1990) stated that the reduction of biomass of plants was directly associated with Cd toxicity. Similar results were also observed by Verma and Dubey (2002). They reported that with elevated levels of Cd in growth media declined the growth and yield of plants. In addition, Cd diminishes the elongation of both shoot and root, and dry matter production by plants, primarily due to hamper of photosynthetic activity as stated by Azevedo *et al.* (2005). And, it is important to note that the elevated Cd levels substantially influence plant mineral nutrition, and a negative correlation remain in the uptake and distribution of various macro and micro-nutrients in various plant parts (Shukla *et al.*, 2003; Drazic *et al.*, 2004; Adhikari *et al.*, 2006; Ghnaya *et al.*, 2007 and Wahid *et al.*, 2008).

Kibria *et al.* (2006) and Muramoto *et al.* (1990) revealed that Cd treatment significantly affected the biomass production of rice. On the other hand, Bingham and Page (1975) observed that Cd concentration (< 3 ppm) in edible tissue of greenhouse soil-grown plants reduced 50% yield of field bean, paddy rice, upland rice, sweet corn. Likewise, Liu *et al.* (2010) reported that 50 mg/kg Cd concentration in soils effectively inhibited rice growth and reduced rice grain yield substantially. Accordingly, Kuzovkina *et al.* (2004) revealed that Cd was strongly phytotoxic and caused rapid death of plants. Then again, Haghiri (1973) noted that Cd toxicity in soybean and wheat begun to occur at soil Cd levels as low as 2.5 ppm (soil pH 6.7). Liu *et al.* (1998) suggested that brown and polished rice being Cd-contaminated when the soil Cd concentration is higher than 2 mg/kg.

Cadmium induced leaf chlorosis appear due to antagonistic effect of cadmium on the uptake of iron, phosphorus, manganese, zinc and copper, causing their deficiencies particularly in the cadmium sensitive varieties (Alcantara *et al.*, 1994; Epstein and Bloom, 2005; Chen *et al.*, 2007). It appears that the same metal transporters are employed for Cd as for other metal ions

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(Sharma *et al*., 2004). Root membrane transporters involved in uptake of K, Ca and Mg are the first targets of cadmium toxicity (Mengel *et al*., 2001).

4.2.2.2 *Nitrogen contents in grains, straw and roots*

The N concentrations in grains, straw and roots of Brridhan- 28 rice as affected by Cd-toxicity have been presented in Appen.Table- 12 and Figure- 4.9. The results were statistically significant at 1% level and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

Nitrogen concentration in the grains of Brridhan- 28 rice ranged from 1.12 to 1.88 %. And the corresponding values were 1.88, 174, 1.64, 1.54, 1.42, 1.26 and 1.12%, respectively at T0 (control), T1, T2, T3, T4, T5 and T6 treatments. Nitrogen concentration in the straw of rice varied from 1.09 to 1.55%, whereas the contents in the roots of rice ranged from 0.49 to 0.95%. N contents in straw of rice at control (T0) and T1, T2, T3, T4, T5 and T6 treatments were 1.55, 1.46, 1.39, 1.36, 1.29, 1.17 and 1.09%, correspondingly. On the other hand, N contents in the roots of Brridhan- 28 rice were 0.95, 0.91, 0.87, 0.83, 0.74, 0.56 and 0.49 %, respectively at T0 (control) and T1, T2, T3, T4, T5 and T6 treatments. In grains, straw and roots, the highest N content was found at control (T0) and the lowest was found at T6 treatment, where 30 mg/kg Pb was applied. A significant reduction of N content was found at T1 treatment, where 3 mg/kg Cd was applied and continued upwards over control. But, at higher concentration (T7: 60 mg/kg; T8: 90 mg/kg), caused death of rice plant. As a matter of fact, N concentration in grains, straw and roots at T1, T2, T3, T4, T5 and T6 treatments were significantly different from control (T0) and also from each other as well.
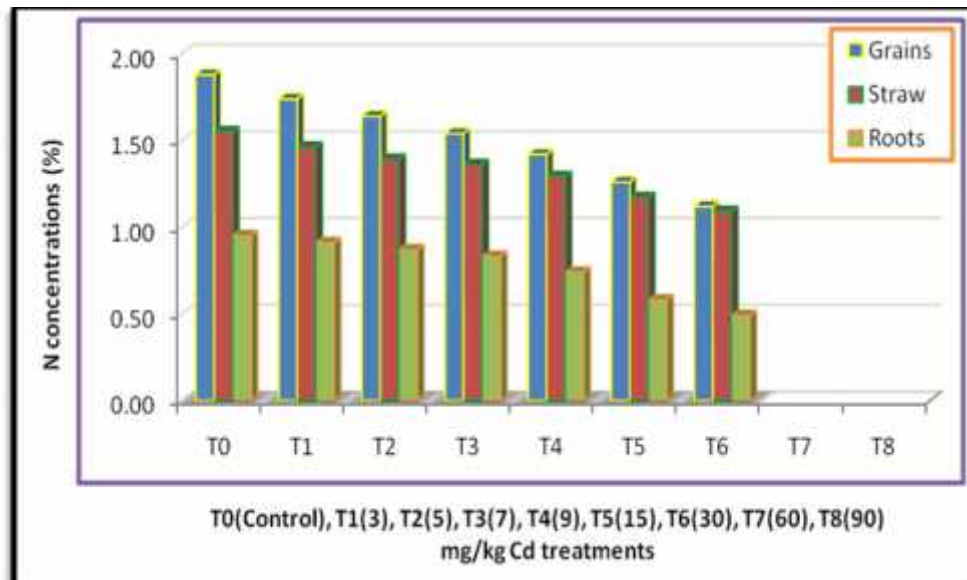
Figure- 4.9: Nitrogen concentration in grains, straw and roots of Brridhan- 28 rice as affected by various treatments of Cd

The results were in agreement with the findings of many authors (Shukla *et al*., 2003; Drazic *et al.,* 2004; Adhikari *et al*., 2006; Ghnaya *et al*., 2007; Wahid *et al*., 2008; Vijayarengan, 2012). They observed that N content in rice decreased with respect to the increased Cd concentrations. Varshney (1990) reported that Hg inhibited N uptake in *Vigna radiata* and Morel *et al*. (1994) found that Cd reduced N uptake in tomato. Similar findings were also reported by Gomes *et al*. (1985). They revealed that the uptake of N from soil was inhibited by the presence of heavy metals. Cd depressed N uptake in plants, which was stated by Iwai *et al*. (1975) and Cunningham (1977). On the other hand, Vijayarengan (2012) concluded that Cd could attribute to decrease in the uptake of N from the soils to rice plants.

4.2.2.3 *Phosphorus concentration in grains, straw and roots*

Phosphorus contents in grains, straw and roots of Brridhan- 28 rice as affected by Cd-toxicity are presented in Appen.Table- 12 and Figure- 4.10. The results were statistically significant at 1% level and the test significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

Phosphorus contents in the grains of Brridhan- 28 rice varied from 0.17 to 0.49% and P concentration in the straw of rice ranged from 0.17% to 0.41%. In the grains, the corresponding P concentration at T0 (control), T1, T2, T3, T4, T5 and T6 treatments were 0.49, 0.32, 0.30, 0.27, 0.23, 0.20 and 0.17%, in that order. On the other hand, the corresponding P contents in the straw were 0.41, 0.34, 0.31, 0.27, 0.23, 0.29 and 0.17%, respectively at control (T0) and T1, T2, T3, T4, T5 and T6 treatments. And in the roots, it ranged from 0.07% to 0.23%. The values were 0.23, 0.18, 0.17, 0.14, 0.12, 0.09 and 0.07%, respectively at T0 (control) and T1, T2, T3, T4, T5 and T6 treatments. The highest concentration was found at control and the lowest was recorded at T6 treatment, where 30
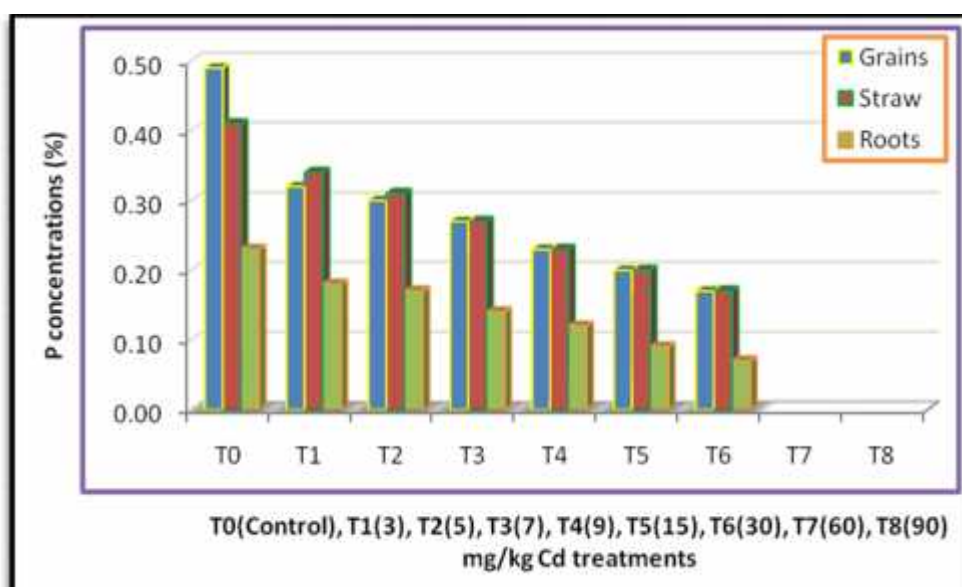
**Figure- 4.10: Phosphorus concentrations in grains, straw and roots of Brridhan- 28
as affected by various treatments of Cd**

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mg/kg Cd was applied. In grains, straw and roots, a significant reduction of P content was initiated at T1 treatment and continued upwards.

In fact, P concentrations in grains, straw and roots at control (T0) and T1, T2, T3, T4, T5 and T6 treatments were found significantly different from each other. And, no plant survived at the treatments T7 and T8, where the levels of applied Cd were 60 and 90 mg/kg, respectively. It was observed from the above discussion that with increasing Cd treatments, P concentrations in the grains, straw and roots decreased significantly and at higher concentration, plant death occurred.

The results were in accordance with the earlier reports of Walker *et al*. (1979) in soybean, Bonnet *et al*. (2000) in rye grass (*Lolium prenne*), Vijayarengan (2005) in green gram and Vijayarengan (2012) in rice. On the other hand, several researchers (Sukla *et al*., 2003; Drazic *et al*., 2004; Adhikari *et al*., 2006; Wahid *et al*., 2008) reported that P contents in different parts of plants decreased significantly with increasing Cd levels in soils and Cd concentrations in plants. It might be due to the antagonistic effects of Cd with phosphorus. Some other scientists were also revealed that Cd had an antagonistic effect on the uptake of P causing their deficiencies particularly in the Cd- sensitive varieties (Alcantara *et al*., 1994; Epstein and Bloom, 2005 and Chen *et al*., 2007).

4.2.2.4 *Potassium concentrations in grains, straw and roots*

The mean K contents in the grains, straw and roots of Brridhan- 28 rice as affected by Cd are presented in Appen.Table- 12 and Figure- 4.11. The results were statistically significant at 1% level and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

Potassium contents in the grains of Brridhan- 28 rice ranged from 1.54 to 2.53%. The corresponding contents were 2.53, 2.37, 2.19, 2.10, 1.98, 1.79 and 1.54% at control (T0) and T1, T2, T3, T4, T5 and T6 treatments. And, K content in straw of rice ranged from 1.10 to 1.71%, whereas in the roots of rice, it ranged from 0.15 to 0.37%. At control (T0) and T1, T2, T3, T4, T5 and T6 treatments, the corresponding K contents in the straw were 1.71, 1.54, 1.48, 1.42, 1.36, 1.28 and 1.10%, respectively. On the other hand, K contents in the roots at control (T0) and T1, T2, T3, T4, T5 and T6 treatments were 0.37, 0.32, 0.31, 0.28, 0.23, 0.18 and 0.15%, respectively. In the grains, straw and roots, the highest K concentration was found at control (T0) and the lowest was recorded at T6 treatment, where 30 mg/kg Cd was applied.
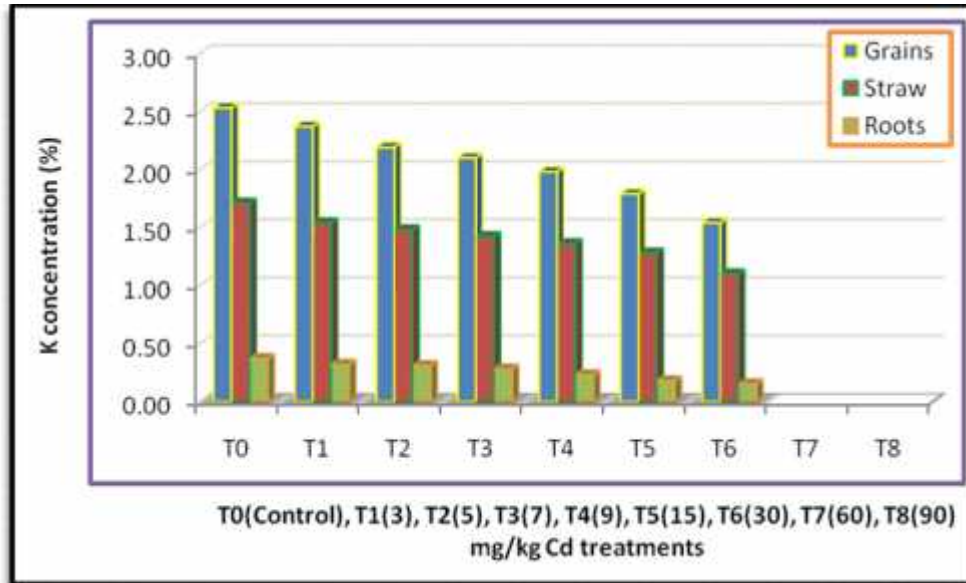
**Figure- 4.11: Potassium concentrations in grains, straw and roots of Brridhan- 28 rice
as affected by various treatments of Cd**

On the other hand, among the treatments, the highest K content was found at T1 treatment, where 3 mg/kg Cd applied and the lowest was obtained at T6. And, at treatments T7 and T8, rice plants could not grow, where 60 and 90 mg/kg Cd were applied, respectively. In fact, when compared with control, K contents in grains, straw and roots at T1, T2, T3, T4, T5 and T6 treatments were significantly different from each other. It was evident from the above discussion that Cd had an antagonistic effect on the accumulation of K by rice plants.

The results were in consonance with the findings of Vijayarengan (2012). He found an antagonistic effect of Cd on K uptake in rice. Likewise, Gussarsson (1994) reported that Cd reduced K uptake in *Betula pendula*. Similarly, Gerzabeck and Edelbauer (1986) observed that Al inhibited K uptake in *Zea mays*. On the other hand, Koucik *et al*. (2006) noticed that low levels of Cd promoted K uptake, but higher levels stimulated K leakage from the root in Cd tolerant but non-hyperaccumulator *Matricaria chamomilla* plants.

4.2.2.5 *Calcium concentration in grains, straw and roots*

Calcium contents in the grains, straw and roots of Brridhan- 28 rice as affected by Cd-toxicity are presented in Appen.Table- 13 and Figure- 4.12. The contents in grains, straw and roots were statistically significant at 1% level and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5 % level.

Calcium contents in the grains, straw and roots of Brridhan- 28 rice varied from 0.20 to 0.52%, 0.51 to 0.85% and 0.09 to 0.28%, respectively. At control (T0) and T1, T2, T3, T4, T5 and T6 treatments, the corresponding concentrations in the grains were 0.52, 0.44, 0.38, 0.35, 0.31, 0.26 and 0.20%, respectively. And in the straw, Ca contents at control (T0) and T1, T2, T3, T4, T5 and T6 treatments were 0.85, 0.77, 0.72, 0.67, 0.65, 0.56 and 0.51%,

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respectively. And in the roots, the related values were 0.28, 0.19, 0.17, 0.15, 0.14, 0.10 and 0.09%, respectively at T0 (control), T1, T2, T3, T4, T5 and T6. A reducing trend of Ca contents in the grains, straw and roots of Brridhan- 28 rice was initiated significantly at T1 treatment, where 3 mg/kg Cd was applied and continued up to T6 treatment. On the other hand, the highest Ca content in the grains, straw and roots of rice was obtained at control (T0) and the lowest was obtained at T6 treatment, where 30 mg/kg Cd was applied.
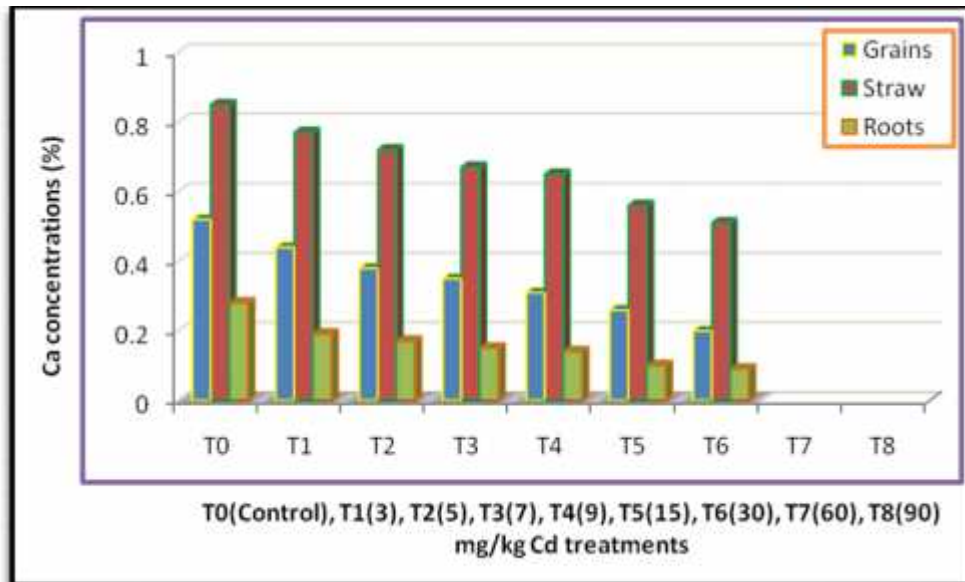
Figure- 4.12: Calcium concentrations in grains, straw and roots of Brridhan- 28 rice as affected by different treatments of Cd

As a matter of fact, Ca concentration in grains, straw and roots at control (T0) and T1, T2, T3, T4, T5 and T6 treatments were significantly different from each other. It is important to note that at treatments T7 (60 mg/kg) and T8 (90 mg/kg) death of rice plant occurred. And, an antagonistic effect was observed between applied Cd and Ca contents in the different parts of rice crops.

These results were in agreement with the findings of Bonnet *et al*. (2000) and Vijayarengan (2012) in rice. Similarly, Stoyanova and Doncheva (2002) found an antagonistic effect of Ca with Zn. On the other hand, Mengel *et al*. (2001) reported that the first target of Cd toxicity was to reduce the transport and uptake of K, Ca and Mg through the root membrane of plant. And, the decrease in Ca content in excess of these metals might be due to antagonistic action of Ca with Cd. Some other researchers (Iwai *et al*., 1975; Root *et al*., 1975; Cunningham, 1977) also concluded that Cd could depress the uptake of Ca.

4.2.2.6 *Magnesium concentration in grains, straw and roots*

The mean contents of Mg in the grains, straw and roots of Brridhan- 28 rice as affected by Cd-toxicity have been presented in Appen.Table- 13 and Figures- 4.13. The results were statistically significant at 1% level and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

 Magnesium contents in the grains of Brridhan- 28 rice varied from 0.31 to 0.67% and the contents in the straw of rice varied from 0.42 to 0.70%, whereas in roots of rice, it was varied between 0.07 and 0.24%. Mg contents in the grains were 0.67, 0.62, 0.57, 0.54, 0.49, 0.39 and 0.31%, correspondingly at control (T0), T1, T2, T3, T4, T5 and T6 treatments. But, in the straw, the values were 0.70, 0.66, 0.64, 0.58, 0.55, 0.48 and 0.42%, respectively at control (T0) and T1, T2, T3, T4, T5 and T6 treatments. In the roots, at control (T0) and T1, T2, T3, T4, T5 and T6 treatments, the concentrations were 0.24, 0.19, 0.16, 0.13, 0.11, 0.09 and 0.07%, in that order. The highest concentration was found at control (T0) and the lowest was recorded at T6 treatment, where 30 mg/kg Cd was applied. The significant reduction was initiated at T1 treatment, where 3 mg/kg Cd was applied and progressively reduced till T6 treatment. But, the rice plants died at T7 and T8 treatments, where 60 and 90 mg/kg Cd was applied, respectively. In fact, Mg contents in the grains, straw and roots of control (T0) and T1, T2, T3, T4, T5 and T6 treatments were found significantly different from each other. It was evident that Mg content in grains, straw and roots of rice decreased significantly with an increased Cd levels in soil.
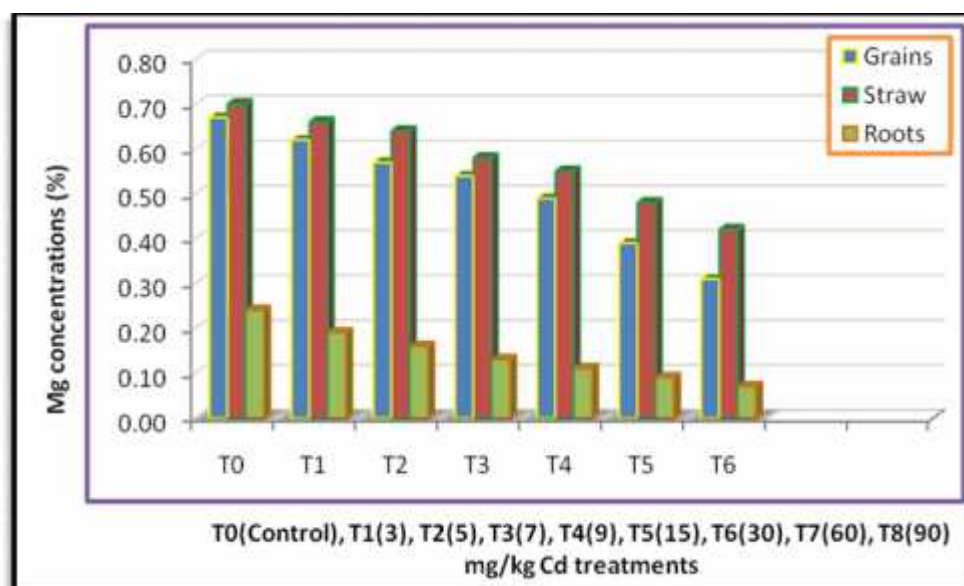
Figure- 4.13: Magnesium concentrations in grains, straw and roots of Brridhan-28 as affected by different treatments of Cd

It was in accordance with the earlier reports of Vijayarengan (2012) and Gussarasson (1994). They reported that Cd treatment depressed Mg contents in plants. On the other hand, Lindon and Henriques (1993) and Ouzounidou (1994) found it under Cu treatment. Similarly, Bonnet *et al*. (2000) and Stoyanova and Doncheva (2002) observed that Zn treatment reduced the Mg accumulation by plants and Dinev and Stancheva (1993) found it under Al treatment. Several scientists (Iwai *et al*., 1975; Root *et al*., 1975; Cunningham, 1977) further reported that the reduction of Mg concentration and uptake by plants might be due to Cd stress. In contrast, Agarwal *et al*. (1987) revealed that the increased Cd treatments decreased Mg content, which might be due to the replacement of Mg from the chlorophyll by the metals.

4.2.2.2.7 *Cd concentrations in grains, straw and roots*

Cadmium is 20 times more toxic to plants than Pb (Adriano, 1986). Cadmium concentration in the grains, straw and roots of Brridhan- 28 rice as affected by different levels of Cd are presented in Table- 4.9 and Figure- 4.14. The results were statistically significant at 1% level and the test of significance of different treatment means was computed by Duncan's Multiple Range Test (DMRT) at 5% level.

The mean values of Cd concentration in the grains, straw and roots of Brridhan- 28 rice ranged from 0.0 to 3.51 mg/kg, 0.30 to 29.30 mg/kg and 1.64 to 211.65 mg/kg, respectively (Table- 4.9). The corresponding mean values in the grains were 0.0, 0.42, 0.53, 0.62, 1.14, 2.86 and 3.51 mg/kg, respectively at control (T0) and T1, T2, T3, T4, T5 and T6 treatments. At control (T0) and T1, T2, T3, T4, T5 and T6 treatments, Cd contents in the straw were 0.30, 4.73, 6.81, 7.87, 8.98, 13.47 and 29.30 mg/kg, accordingly. And in the roots, the values were 1.64, 42.74, 53.92, 63.62, 77.03, 100.00, 211.65 mg/kg, respectively at control (T0) and T1, T2, T3, T4, T5 and T6 treatments. The highest content was found at T6 treatment, where 30 mg/kg Cd was applied and the lowest was found at control (T0).

Table- 4.9: Concentrations and transfer co-efficient of Cd in grains, straw and roots of Brridhan -28 rice as affected by Cd-toxicity

Treatment denotations	Applied Cd (mg/kg)	Cd Concentrations					
		Grains		Straw		Roots	
		Conc. (mg/kg)	TC	Conc. (mg/kg)	TC	Conc. (mg/kg)	TC
T0	Control	0.00 a C	-	0.30 a B	-	1.64 a A	-
T1	3	0.42 b C	0.14	4.73 b B	1.58	42.74 b A	14.28
T2	5	0.53 c C	0.11	6.81 c B	1.36	53.92 c A	10.77
T3	7	0.62 d C	0.09	7.87 d B	1.12	63.62 d A	9.09
T4	9	1.14 e C	0.13	8.98 e B	1.00	77.03 e A	8.56
T5	15	2.86 f C	0.19	13.47 f B	0.90	100.0 f A	6.67
T6	30	3.51 g C	0.12	29.30 g B	0.98	211.65 g A	7.05
T7	60	-		-	-	-	
T8	90	-		-	-	-	

Mean values with the same letter in the same row (capital letter) and same column (small letters) are not significantly different (p=0.05)

Cd concentrations in grains, straw and roots increased considerably and significantly with increasing Cd application over control (Figure- 4.14). However, Cd contents in the grains, straw and roots of control (T0) and T1, T2, T3, T4, T5 and T6 treatments were found significantly different from each other. But, plant death occurred at treatments T7 and T8, where 60 and 90 mg/kg Cd was applied.

It was observed from the above discussions that the fresh weight, dry weight and grain yield of rice had been significantly and increasingly affected with increasing Cd treatments. Conversely, an increasing trend of Cd was found concentration increased significantly with increasing Cd levels in soils (Figure- 4.14). On the other hand, the transfer co-efficient of Cd in grains, straw and roots of rice from soil ranged from 0.09 to 0.19, 0.90 to 1.58 and 6.67 to 14.28, respectively (Table- 4.9). And, the bulk of the Cd remained in the roots of rice crops. However, Cd contents in different parts of rice exhibited the following descending order: Roots > straw > grains.
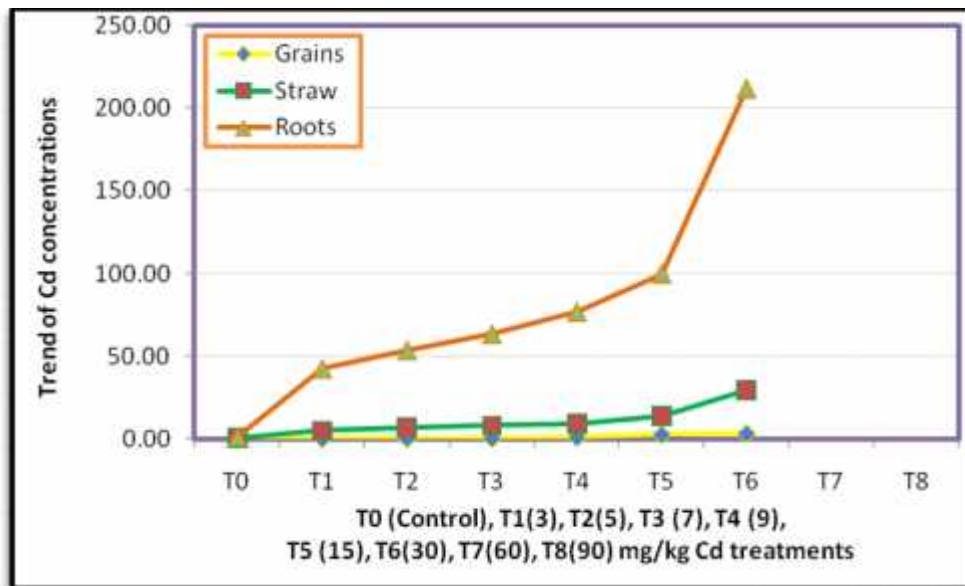
Figure- 4.14: Trend of Cd concentrations in grains, straw and roots of Brridhan- 28 as affected by different levels of Cd

The results were in accordance with the findings of several researchers (Liu *et al*., 2003b; Kibria *et al*., 2006; Vijayarengan, 2012). They found an increasing trend of Cd concentration in rice with increasing Cd application. Vijayarengan (2012) conducted a pot experiment with various levels of exogenous Cd (0, 10, 20, 30, 40, 50 mg/kg soil) and found that the accumulation of Cd in rice plants increased with an increase in Cd in soil at all levels. On the other hand, Jiang *et al*. (2004) revealed that Cd accumulation in both shoots and roots of Indian mustard increased with increasing soil Cd treatments. Then again, Pinto *et al*., (2004) reported that Cd is one of the most toxic and mobile metallic elements in soil and is a potential contaminant of soil and environment. Cadmium salts are highly water soluble and Cd in ionic form is highly mobile within the phloem and, therefore, easily translocated to

various plant parts (Mengel *et al.*, 2001 and Pinto *et al.*, 2004). Generally, Cd is taken up through the roots and accumulated mainly in the organ, but it can be translocated to shoots, grains and fruits (Page *et al.*, 1981); but maize roots have a great ability to retain Cd (Nicito *et al.*, 2002). Kibria *et al.* (2006) reported that Cd concentrations in different plant parts followed the order: grain < shoot < root. In addition, Shaw and Panigrahi (1986) and Fergusson (1990) reported more elaborately that the concentration level of a metal generally decreases in the following order: root > stem > leaves > fruit > seed, when the source of metal is only the soil. Similar results were also revealed by Ullah *et al.* (1999) and Vijayarengan (2012). They observed that rice accumulated more metals in roots than in straws. Adriano (2001) stated that the total soil Cd concentration could not be considered reliable to determine whether rice grains are safe for consumers.

4.2.3 Growth, Yield, Mineral Nutrition and Pb Concentrations of Five Different Rice Varieties as Affected by 200 mg/kg Applied Pb (Experiment- 2a)

4.2.3.1 *Fresh weight, dry weight and grain yield*

The effects of 200 mg/kg Pb on the growth and the physical appearance of 60 days old five different rice varieties over control have been depicted presented in Plate- 15. The mean values of fresh and dry weight of rice plants as well as grain yield (g/pot) of five different high yielding rice varieties (BR-15, BR-16, BR-19, Brridhan- 29 and Brridhan- 45) as affected by 200 mg/kg applied Pb are presented in Table- 4.10. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found significant at 1% level. But, in paired samples T- test, the fresh weight, dry weight and grain yield of BR-16, BR-19, BR-29 and BR-45 rice varieties were found insignificant, whereas BR-15 rice variety was found highly significant (1% level) over control (Appen.Table- 14).

Plate- 15: The growth and physical appearance of five different rice varieties as affected by Pb
(200 mg/kg soil) treatment over control

The fresh weight of five different rice varieties under investigation ranged from 128.30 to 185.70 g/pot (Table- 4.10). The highest fresh weight was obtained in BR- 19 (185.70 g/pot) followed by Brridhan- 45 (181 g/pot) and the lowest was obtained in BR- 15 (128.30 g/pot) rice variety. In fact, the fresh weight of V3 and V4 rice varieties was found statistically similar, whereas V1, V2 and V5 varieties were significantly different from each other and also from V3 and V4 rice varieties (Table- 4.10). On the other hand, the percent fresh weight reduction ranged from 0.66 to 19.50 % (Appen.Table- 14 and Figure- 4.15). The highest reduction was found in BR- 15 rice variety and the lowest was found in BR- 16 rice variety over control. Similarly, the dry weight of all five varieties of rice ranged from 28.19 to 40.0 g/pot (Table- 4.10). The highest dry weight was obtained in BR- 19 (40 g/pot), followed by Brridhan- 45 (38.50 g/pot) and the lowest was obtained in BR- 15 (29.19 g/pot) rice variety. As a matter of fact, the dry weights of V3 and V4 varieties were statistically similar, whereas V1, V2 and V5 varieties of rice were significantly different from each other and also from V3 and V4 (Table- 4.10). Then again, the percent reduction of dry weight ranged from 2.68 to 18.29% over control (Appen.Table- 14 and Figure- 4.15). The highest dry weight reduction was obtained in BR- 15 rice variety and the lowest was found in Brridhan- 45 rice variety over control.

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Table- 4.10: Fresh weight, dry weight and grain yield (g/ pot) of five different rice varieties as affected by applied Pb (200 mg/kg soil)

Rice Varieties		Fresh Weight (g/pot)	Dry Weight (g/pot)	Grain Weight (g/pot)
Denotations	Names			
V1	**BR-16**	151.00 c	30.81 c	66.10 c
V2	**BR-15**	128.30 d	28.19 d	46.98 d
V3	**BR-19**	185.70 a	40.00 a	76.87 a
V4	**Brridhan-45**	181.00 a	38.50 a	71.50 b
V5	**Brridhan-29**	169.30 b	34.43 b	70.13 bc
CV	-	1.89%	2.59%	2.40%

Mean values with the same letter in the same column are not significantly different (p=0.05)
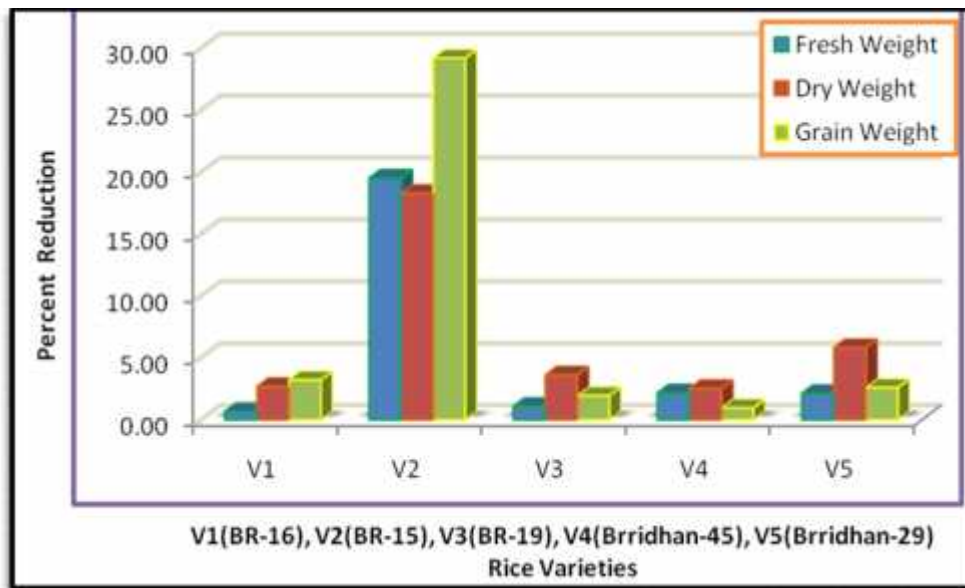
Figure- 4.15: Percent reduction of fresh weight, dry weight and grain yield of five varieties of rice as affected by applied Pb (200 mg/kg soil) over control

Like fresh and dry weight, the grain weight of five different varieties of rice under study ranged from 46.98 to 76.87 g/pot (Table- 4.10). The highest grain yield was obtained in BR-19 (76.87 g/pot), followed by Brridhan- 45 (71.50) and Brridhan- 29 (70.13 g/pot) and the lowest was obtained in BR-15 (46.98 g/pot) rice variety. In fact, the grain weights of V1, V4 and V5 rice varieties were statistically similar, while V1 and V4 varieties were significantly different from each other. On the other hand, V2 and V3 rice varieties were also significantly different from each other and also from V1, V4 and V5 (Table- 4.10). The percent yield reduction ranged from 1.95 to 29.20%, whereas the highest reduction was obtained in BR- 15 and the lowest was obtained in Brridhan- 45 rice variety over control (Appen.Table- 14 and Figure- 4.15).

It was observed that the fresh weight, dry weight and grain yield of five different rice varieties under study were found different, which was due to the effect of applied Pb and the yielding abilities of the cultivars. The percent reduction of fresh weight, dry weight and grain yield was also found different over control. The fresh weight, dry weight and grain weight of BR-16, BR-19, Brridhan- 29 and Brridhan- 45 varieties of rice had not been affected considerably by 200 mg/kg applied Pb, whereas the growth and yield of BR- 15 variety had been significantly affected over control. The results were in agreement with the findings of Liu *et al*. (2003a). They reported that the effect of Pb on the growth and development of rice varied among rice cultivars, where some cultivars were highly retarded, some cultivars were well tolerated and other showed no significant change in straw and grain yield. And, therefore, the sensitivity or susceptibility and tolerance of rice to Pb toxicity were cultivar dependent.

Likewise, Sharma and Dubey (2005) reported that plant species differed in Pb tolerance showing various behaviors of certain enzymes under Pb treatment. On the other hand, Igoshene and Kositsin (1990), while studying the effect of Pb on carbohydrage activities in the tolerant and sensitive species of melic-grass (*Melica nutans*) observed that in tolerant melic-grass population, Pb activated carbohydrage activity, whereas in the sensitive plants the activity of this enzyme remained unaffected. Then again, Yang *et al*. (2000) revealed that Pb tolerant rice (*Oryza sativa*) varieties can ameliorate Pb toxicity due to the release of oxalate, citrates and malates.

Tzerakis *et al*. (2012) and Fernandez *et al*. (2012) conducted an experiment with *Melilotus officinalis* and *Melilotus alba* and reported that under metal toxicity conditions, significant differences in biomass production between different species of the same genus existed. They also reported that *Melilotus officinalis* showed more tolerant to Pb than *Melilotus alba,* because no differences in shoot or root length, or number of leaves were found between control plants and those grown under 200 and 1000 mg/kg Pb. They further added that under metal toxicity conditions biomass production was also related with the genotypic differences between cultivars of the same species. On the other hand, the internal tolerance mechanisms of Pb are immobilization, compartmentalization, or detoxification of metals in the symplasm by using metal binding compounds (Hamer, 1986; Rauser, 1990; Hauslander and Alscher, 1993; Grotz *et al*., 1998). Lee and Kim (1991) reported a decrease in dry matter yield of rice straw with the increased application of Pb. Chatterjee *et al*. (2006) also reported that excess Pb reduced dry weight and grain yield of rice. Moreover, many researchers (Wolnik *et al*., 1983; Hibben *et al*., 1984; Moser, 1986; Sameni *et al*., 1987; Juma and Tabatabai, 1988; Ullah and Gerzabek, 1991; Patel *et al*., 1996) reported that due to the presence of heavy metals yield reduction of crops occurred.

4.2.3.2 *Nitrogen contents in grains, straw and roots*

The mean values of N contents in grains, straw and roots of the five rice varieties under study as affected by 200 mg/kg applied Pb are presented in Appen.Table- 15 and Figure- 4.16. Nitrogen contents in the grains, straw and roots were found significant at 1% level. But in paired sample T- test, N content in grains of BR- 15 variety was found significant at 1% level, whereas in straw and roots, it was found significant at 5% level over control. On the other hand, N content in the grains, straw and roots of BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45 was found insignificant over control (Appen.Table- 17).

Nitrogen concentrations in grains of the rice varieties under investigation ranged from 1.42 to 1.79%. The lowest concentration was found in the grains of BR- 15 (1.42%), followed by BR- 16 (1.49%) and the highest was found in BR- 19 (1.79%) rice variety. In fact, N in the grains of V1, V2, V4 and V5 varieties was found statistically similar. On the other hand, V2 and V4 and V2 and V5 varieties were significantly different from each other. Likewise, V3 variety was significantly different from four other rice varieties. Nitrogen concentrations in the straw of different rice varieties ranged from 1.20 to 1.36%. The lowest concentration was found in BR- 15 (1.20%), followed by BR- 16 (1.21%) and the highest was found in BR- 19 (1.36%) rice variety. As a matter of fact, N contents in the straw of V1, V2, V3, V4 and V5 rice varieties were significantly different from each other.

Like grains and straw, N concentrations in the roots of different rice varieties under study ranged from 0.69 to 0.84% and the highest N was found in BR- 19 (0.84%) rice variety, followed by Brridhan- 45 (0.82%) and the lowest was found in BR- 16 (0.69%) rice variety.

Figure- 4.16: N concentrations in grains, straw and roots of five different varieties of rice as affected by applied Pb (200 mg/kg soil)

In fact, N contents in the roots of V1, V2, V3, V4 and V5 varieties were found significantly different from each other.

Among the five rice varieties, a significant reduction of N content was found in the grains, straw and roots of BR- 15 rice over control, whereas four other varieties remained unaffected by 200 mg/kg Pb treatment. On the other hand, a variation in N concentration was observed in grains, straw and roots of all the five varieties of rice. The results were in accordance with the findings of several authors (Jiang, 2006; Karim *et al*., 2012; Chatzistathis *et al*., 2012). They found a wide variation in nutrient utilization efficiency among genotypes of the same plant species. Then again, Liu *et al*. (2003a) observed that the tolerance capacity of Pb stress on crops varied among the different cultivars of the same species of rice. Similarly, Strand *et al*. (1990) reported that the effect of Pb on rice was found variety dependent. On the contrary, Lee and Kim (1991) reported an antagonistic effect on N uptake by rice plants due to applied Pb. Ullah *et al*. (2011) observed that Pb reduced the uptake of N by rice. Similar finding was also reported by Sharma and Dubey (2005). They reported that the entry of NO_3^- in the root systems of plants was inhibited by Pb.

4.2.3.3 *Phosphorus contents in grains, straw and roots*

The mean values of P concentrations in the grains, straw and roots of different varieties of rice under study as affected by 200 mg/kg applied Pb are presented in Appen.Table- 15 and Figure- 4.17. Phosphorus content in the grains, straw and roots of different varieties of rice was found highly significant (1% level). But, in paired sample T- test, P concentration in the grains and roots of BR- 15 rice variety was found significant at 5% level, whereas in straw it was found highly significant (1% level) over control. On the other hand, P content in the grains, straw and roots of BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45 was found insignificant over control (Appen.Table- 17).

Phosphorus content in the grains of the test crops ranged from 0.27 to 0.40%. The highest concentration was found in Brridhan- 29 (0.40%), followed by BR- 19 (0.37%) and the lowest was found in BR- 15 (0.27%) rice variety. As a matter of fact, P in the grains of V1 and V4 rice varieties was found statistically similar, while V2, V3 and V5 rice varieties were significantly different from each other and also from V1 and V4. Similarly, P in the straw of the test rice crop varieties ranged from 0.31 to 0.42% and the highest concentration was found in Brridhan- 45 (0.42%), followed by BR- 19 (0.41%) and the lowest was found in BR- 15(0.30%) rice variety. On the other hand, P concentration in the straw of V1 and V5 varieties were statistically similar, whereas V2, V3 and V4 varieties were found significantly different from each other and also from V1 and V5 rice varieties. Like grain and straw, P contents in the roots of different rice varieties ranged from 0.16 to 0.30%. The highest concentration was found in BR- 19 (0.30%), followed by Brridhan- 45 (0.29%) and the lowest was found in BR- 15 (0.16%) rice variety. Moreover, a significant variation in P concentration was found among V1, V2, V3, V4 and V5 rice varieties.
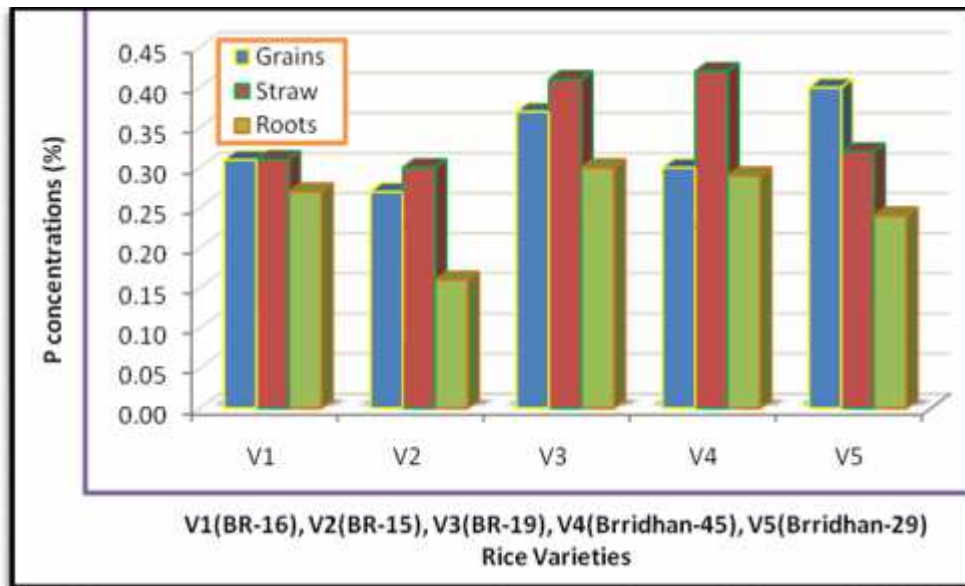
**Figure- 4.17: P concentrations in grains, straw and roots of five different varieties
of rice as affected by applied Pb (200 mg/kg soil)**

It was evident that the highest P contents was found in the grains of BR- 29 rice and the straw of BR- 45 and roots of BR-19 rice, but the lowest was found in the grains, straw and roots of BR- 15 rice. Many researchers (Baligar *et al*., 2001; Aziz *et al*., 2011 and Yang *et al*., 2011) agreed with the similar findings. On the other hand, a minor reduction of P content was found in the grains, straw and roots of all five varieties of rice, but a significant reduction was found in BR- 15 rice variety over control. It might be due to the tolerance ability of rice against Pb stress. It is important to notice that there was a variation in the effect of Pb on the growth and development of five different rice varieties. The results were in accordance with Liu *et al*. (2003a). Gigliotte *et al*. (1990) reported that the uptake of P by rice and other plants were decreased significantly due to the adverse and antagonistic effects of Pb. Similar finding was also reported by Frostegard *et al*. (1993). Likewise, Walker *et al*. (1997) observed that Pb decreased the uptake of P in *Zea mays* and Paivoke (2002) found a negative correlation of Pb with P.

4.2.3.4 *Potassium contents in grains, straw and roots*

The mean values of K concentrations in the grains, straw and roots of five different varieties of rice under study as affected by 200 mg/kg applied Pb are presented in Appen.Table- 15 and Figure- 4.18. K contents in the grains, straw and roots of the test crop varieties were found significant at 1% level. But, in paired samples T- test, K concentration in the grains and roots of BR- 15 rice variety was found highly significant (1% level) and in straw, it was found significant at 5% level over control. On the other hand, K content in the grains, straw and roots of four other varieties (BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45) was found insignificant over control (Appen.Table- 18).
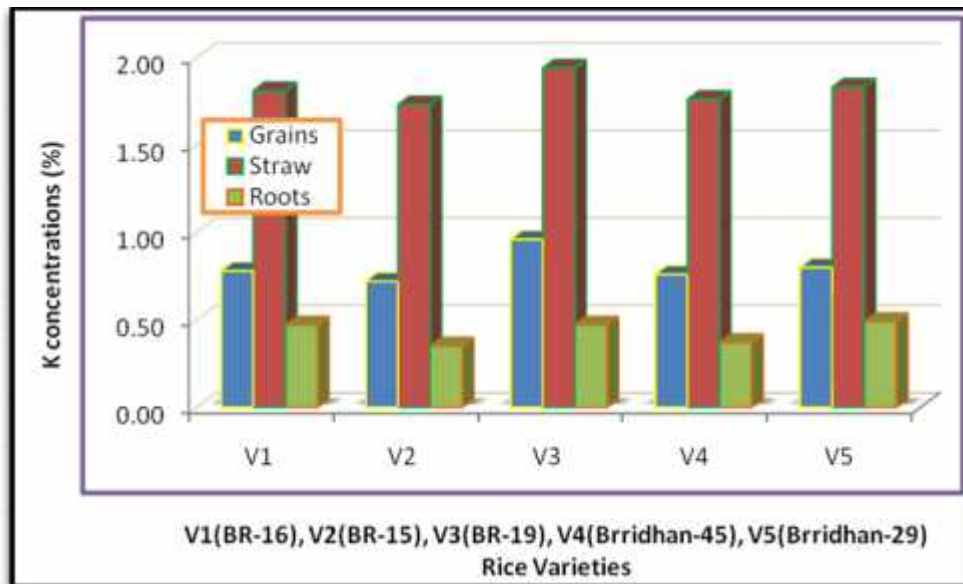
Figure- 4.18: K concentrations in grains, straw and roots of five different varieties of rice as affected by applied Pb (200 mg/kg soil)

Potassium concentrations in the grains of test crops ranged from 0.72 to 0.96%. The highest concentration was found in BR- 19 (0.96%) and the lowest was found in BR- 15 (0.72%) rice variety. In fact, K contents in the grains of V1, V2, V3, V4 and V5 rice varieties were found significantly different from each other. Similarly, K contents in the straw of five rice varieties ranged from 1.73 to 1.94%. The highest concentration was found in BR- 19 (1.94%) and the lowest was found in BR- 15 (1.73%) rice variety. As a matter of fact, K concentration in the straw of V1, V2, V3, V4 and V5 varieties was also found significantly different from each other. Like grains and straw, K contents in the roots of the test crop varieties ranged from 0.35 to 0.49%. The highest concentration was found in the roots of Brridhan- 29 (0.49%) and the lowest was found in BR- 15 (0.35%) rice variety. But, K contents in the roots of V1 and V3 rice varieties were statistically similar, whereas V2, V4 and V5 varieties were significantly different from each other and also from V1 and V3 rice varieties.

It was evident from the results that the highest K concentration was found in the grains and straw of BR- 19 and the roots of BR- 29, while the lowest was obtained in the grains, straw and roots of BR- 15 rice variety. On the other hand, a slight reduction of K concentration was obtained in the grains, straw and roots of BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45 rice varieties, while a significant reduction was observed in the grains, straw and roots of BR- 15 rice variety over control. It was noticeable that K content in the grains, straw and roots of different rice varieties was found different, which might be due to their varietal differences, K accumulating nature and metal effect. Moreover, it was also obvious that the effect of Pb on K was found variety dependent. The result was in consonance with Chatzistathis *et al*. (2009) and Karim *et al*. (2012). They found a significant variation in nutrient use efficiency among genotypes (cultivars) of the same plant. On the contrary, Liu *et al*., (2003a) reported that the effect of Pb on crops was variety dependent. Then again, Trivedi and Erdei (1992) reported

that Pb concentration had an adverse impact on K uptake in rice. Similar finding was also reported by Ullah *et al.* (2011). They revealed that increased Pb levels in soils significantly decreased K in the grains and straw of rice. Likewise, Khan and Khan (1983) observed an antagonistic effect in the uptake of K with Pb in tomato and eggplant. Similarly, Sharma and Dubey (2005) observed that the entry of K was inhibited by Pb- toxicity in the root system of rice in most cases.

4.2.3.5 *Calcium contents in grains, straw and roots*

The mean values of Ca contents in grains, straw and roots of five different rice varieties under study as affected by 200 mg/kg applied Pb are presented in Appen.Table- 16 and Figure- 4.19. Calcium content in grains, straw and roots was found significant at 1% level. But in paired samples T- test, Ca content in the grains and roots of BR- 15 rice variety was found highly significant (1% level), whereas straw was found significant at 5% level over control. On the other hand, Ca content in grains, straw and roots of BR-16, BR-19, Brridhan-29 and Brridhan-45 rice varieties was found insignificant over control (Appen.Table- 18).

Calcium contents in grains of rice varieties ranged from 0.67 to 0.89% and the highest concentration was found in BR- 19 (0.89%), followed by BR- 16 (0.83%) and BR- 15 (0.79%) rice varieties. In fact, Ca in the grains of V4 and V5 varieties were found statistically similar, whereas V1, V2 and V3 varieties differed significantly among them and also from V4 and V5 rice varieties. Ca contents in the straw of different rice varieties ranged from 0.69 to 0.96%. The highest concentration was found in Brridhan- 29 (0.96%), followed by Brridhan- 19 (0.95%) and the lowest was found in BR- 15 (0.69%) rice variety.
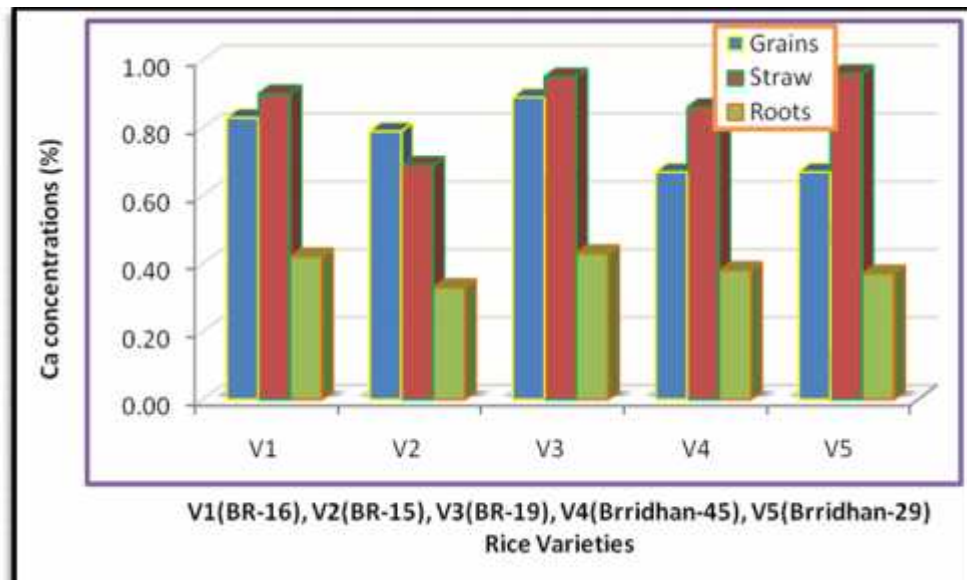
Figure- 4.19: Calcium concentration in the grains, straw and roots of five different varieties of rice as affected by 200 mg/kg applied Pb

As a matter of fact, Ca content in the straw of V3 and V5 were statistically similar, whereas V1, V2 and V4 varieties were significantly different from each other and also from V3 and

V5 rice varieties. Like grains and straw, Ca content in the roots of rice varieties ranged from 0.33 to 0.43%. The highest concentration was found in the roots of BR- 19 (0.43%), followed by BR- 16 (0.42%) and the lowest was found in BR- 15 (0.33%) rice variety. Furthermore, Ca contents in the roots of V1, V2, V3, V4 and V5 varieties were found significantly different from each other.

It was observed that the highest Ca concentration was found in the grains and roots of BR- 19 and the straw of Brridhan- 29 variety, and the lowest was found in the straw and roots of BR- 15 and grains of Brridhan- 45 rice variety. Hence, Ca in grains, straw and roots of the crops under investigation varied among the varieties. The results were in accordance with Yang *et al*. (2011). They found a significant variation in nutrient use efficiency among different varieties of the same species of plants.

A significant reduction of Ca concentration was observed in the grains, straw and roots of BR- 15 rice variety, but a minor reduction was observed in four other rice varieties over control. The results were in agreement with the findings of Liu *et al*. (2003a). They revealed that the susceptibility or tolerance of Pb was variety dependent. On the other hand, Kim *et al*. (1986) reported that Pb concentration in soils retarded Ca concentration significantly in rice plants. Likewise, Pb had an antagonistic effect on Ca uptake in rice plants (Lee and Kim, 1991; Sharma and Dubey, 2005).

4.2.3.6 *Magnesium contents in grains, straw and roots*

The mean Mg contents in the grains, straw and roots of five different rice varieties under study as affected by 200 mg/kg applied Pb are presented in Appen.Table- 16 and Figure- 4.20. Magnesium content in the grains, straw and roots was found significant at 1% level. But in paired samples T- test, Mg content in the grains and roots of BR- 15 rice variety was found significant at 1% level, while the straw was found significant at 5% level over control. On the other hand, Mg content in the grains, straw and roots of BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45 was found insignificant over control (Appen.Table- 19).

Magnesium content in grains of rice varieties under study ranged from 0.45 to 0.71%. The highest content was found in BR- 16 (0.71%) and the lowest was found in Brridhan- 45 (0.45%) rice variety. In fact, Mg content in grains of V2, V3 and V5 varieties were found statistically similar, whereas V1 and V4 varieties were significantly different from each other and also from V2, V3 and V5 rice varieties. Similarly, Mg content in the straw ranged from 0.53 to 0.73%. The highest concentration was found in Brridhan- 29 (0.73%), followed by Brridhan- 45 (0.71%) and the lowest was found in BR- 15 (0.53%) rice variety. Besides, Mg content in the straw of five different varieties varied significantly among them. Like grains and straw, Mg content in the roots ranged from 0.19 to 0.33%. The highest was found in Brridhan- 19 (0.33%), followed by Brridhan- 45 (0.32%) and the lowest was found in BR- 15 (0.19%) rice variety. Moreover, Mg content in the roots of V1, V2, V3, V4 and V5 varieties varied significantly among them.
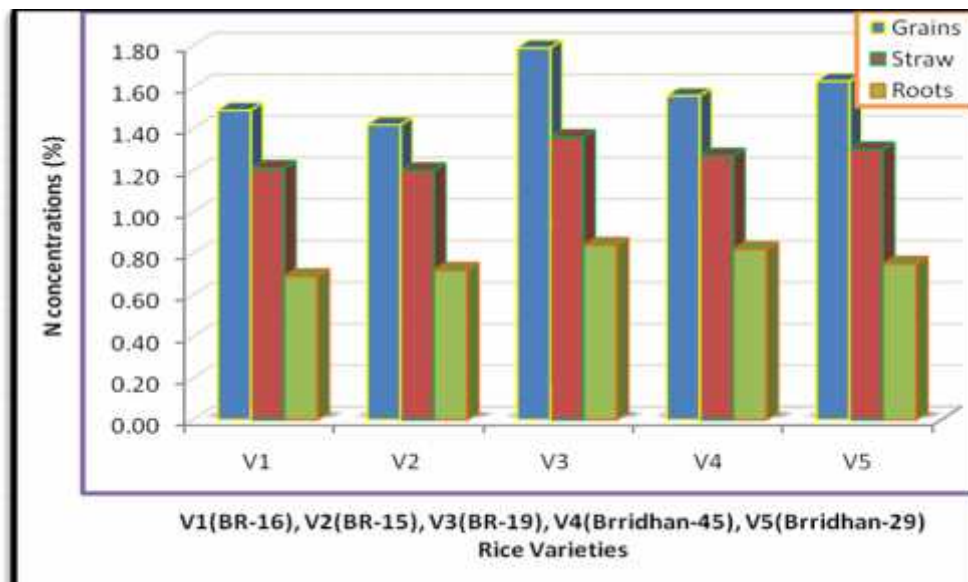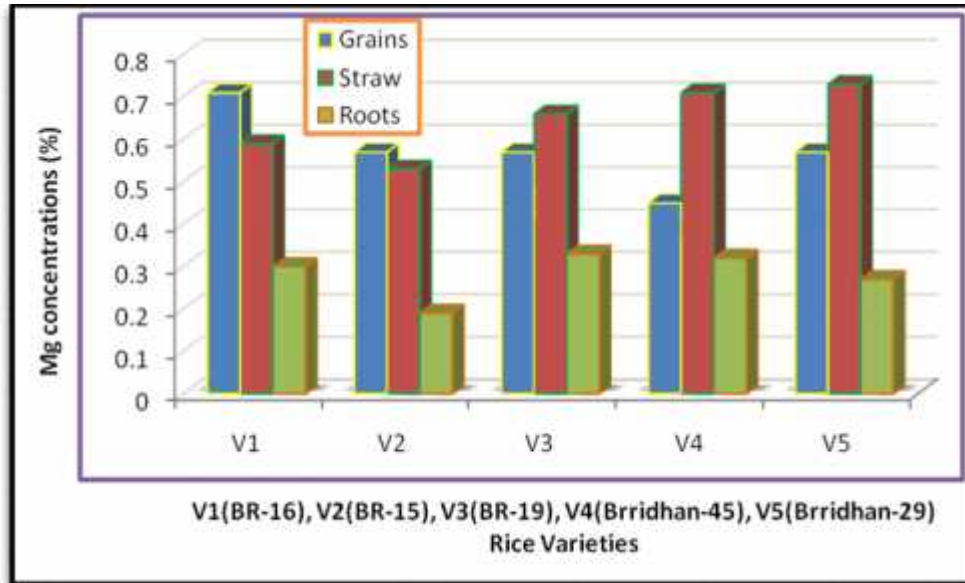
Figure- 4.20: Mg concentrations in grains, straw and roots of five different varieties of rice as affected by applied Pb (200 mg/kg soil)

It was observed from the above results that the highest Mg content was found in the grains of BR- 16 rice variety and the lowest was found in the grains of BR- 45 rice variety. On the other hand, the highest Mg was found in the straw of BR- 29 rice variety and in the roots of BR- 19 rice, whereas the lowest content was found both in straw and roots of BR- 15 rice. Then again, a slight reduction of Ca contents was observed in the grains, straw and roots of BR-16, BR- 19, Brridhan- 29 and Brridhan- 45 rice varieties, but a significant reduction was observed in BR- 15 rice varieties over control. It was also observed that Mg content in the grains, straw and roots of five rice varieties differed among them. And, Pb tolerance capacity was cultivar dependent (Liu *et al*., 2003a). Many researchers found significant variation regarding nutrient utilization efficiency among different cultivars of the same plant species (Aziz *et al*., 2011a; Yang *et al*., 2011; Chatzistathis *et al*., 2012). It was further observed that Pb had a negative effect on Mg uptake by rice crops. Similar results were also observed by many authors in the same field (Kim *et al*., 1986 and Xian, 1989). Likewise, Lee and Kim (1991), Hirayama and Kobayashi (1989) and Sharma and Dubey (2005) observed an adverse effect of Pb on Mg uptake by rice plants.

4.2.3.7 *Pb concentrations in grains, straw and roots*

The mean values of Pb concentrations in the grains, straw and roots of five different rice varieties under study as affected by 200 mg/kg applied Pb are presented in Table- 4.11. The test of significance of the concentration of Pb in straw, grains and roots of different varietal means was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). Likewise, in Paired samples T- test, Pb concentration in the grains, straw and roots was found highly significant (1% level) over control (Appen.Table- 20).

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Pb concentrations in rice grains of five different rice varieties under study ranged from 0.06 to 1.52 mg/kg. The lowest concentration was found in the grains of BR- 19 (0.06 mg/kg), followed by Brridhan- 45 (0.07 mg/kg) and Brridhan- 29 (0.09 mg/kg) and the highest was found in BR- 15 (1.90 mg/kg) rice variety. On the other hand, Pb concentration in the grains of five different rice varieties exhibited the following descending order: V2 (BR- 15) (1.52 mg/kg) >V1 (BR- 16) (0.10 mg/kg) >V5 (Brridhan- 29) (0.09 mg/kg) > V4 (Brridhan- 45) (0.07 mg/kg) >V3 (BR- 19) (0.06 mg/kg). In fact, statistically V1, V3, V4 and V5 rice varieties were similar, while V2 variety was significantly different from four other rice varieties.

Table- 4.11: Concentrations and the transfer co-efficients of Pb in the grains, straw and roots of five different varieties of rice as affected by applied Pb (200 mg/kg soil)

Rice Varieties		Pb Concentrations					
		Grains		Straw		Roots	
Denotations	Name	Conc. (mg/kg)	TC	Conc. (mg/kg)	TC	Conc. (mg/kg)	TC
V1	BR-16	0.10 b C	0.0005	9.50 c B	0.047	260.0 a A	1.30
V2	BR-15	1.52 a C	0.0076	25.50 a B	0.075	215.0 b A	1.08
V3	BR-19	0.06 bC	0.0003	10.77 c B	0.053	176.70 c A	0.88
V4	Brridhan-45	0.07 b C	0.00035	13.53 b B	0.067	170.00 c A	0.85
V5	Brridhan-29	0.09 b C	0.00045	14.93 b B	0.07	166.70 c A	0.83
CV	-	6.63%	-	3.44%	-	4.31%	-

Mean values with the same letter in the same row (capital letters) and the same column (small letters) are not significantly different (p=0.05)

Pb concentrations in the straw of the investigated rice varieties ranged from 9.5 to 25.50 mg/kg. The lowest content was found in the straw of BR-16 (9.50 mg/kg), followed by BR-19 (10.77 mg/kg) and Brridhan- 45 (13.53 mg/kg) and the highest was found in BR- 15 (25.50 mg/kg) rice variety. On the other hand, Pb concentrations in the straw of different rice varieties showed the following order: V2 (BR- 15) (25.50 mg/kg)> V5 (Brridhan- 29) (14.93 mg/kg)> V4 (Brridhan- 45) (13.53 mg/kg)> V3 (BR- 19) (10.77 mg/kg)> V1 (BR- 16) (9.50 mg/kg). As a matter of fact, Pb concentration in the straw of V1 and V3 and V4 and V5 varieties was found statistically similar. On the other hand, V2 rice was found significantly different from V1, V3, V4 and V5 rice varieties.

Pb concentration in the roots of the investigated rice varieties ranged from 166.67 to 260.0 mg/kg. The lowest concentration was found in the roots of Brridhan- 29 (166.67 mg/kg), followed by Brridhan- 45 (170 mg/kg) and Brridhan- 19 (176.70 mg/kg) and the highest was found in BR- 16 (260 mg/kg) rice variety. But, Pb concentration in the roots exhibited the followed descending order: V1 (BR- 16) (260 mg/kg) >V2 (BR- 15) (215.0 mg/kg) > V3 (BR- 19) (176.6 mg/kg) > V4 (Brridhan- 45) (170.0 mg/kg) >V5 (Brridhan- 29) (166.67 mg/kg). Moreover, Pb in the roots of V2, V3 and V4 varieties was found statistically similar, whereas V1 and V2 rice varieties were found significantly different from each other and also

from V3, V4 and V5 rice varieties. The transfer co-efficients of Pb in grains, straw and roots of the rice crops varied from 0.0003 (negligible) to 0.0076, 0.047 to 0.075 and 0.83 to 1.3, respectively (Table- 4.11). On the other hand, Pb concentration in different parts of rice exhibited the following descending order: Roots> Straw> Grains.

Above results showed that Pb concentrations in straw, grains and roots differed markedly among the varieties and also over control of the same variety. Barman *et al*. (1999) revealed that the accumulation of metals in plants varied from species to species and also within the different parts of plants. The highest concentration of Pb was found in the straw and grains of BR- 15 rice and in the roots of BR- 16 rice. Conversely, Pb concentration in the grains of BR-16, BR- 19, Brridhan- 29 and Brridhan- 45 rice varieties was found very low and within the tolerable limit except BR-15 variety, where concentration had exceeded the tolerable limit as described by FAO/WHO (2001) and Norton *et al*. (2014) and which were 0.3 mg/kg and 0.2 mg/kg, respectively.

It might be due to the tolerance capacity of different rice varieties against Pb stress. Sauerbeck (1982) and Baker (1991) mentioned that the metals were poorly transported to the grain tissues. They also recommended that cereal crops such as wheat, barley, oat, rye and corn might be considered as metal excluders. On the other hand, Pb concentration in different parts of rice crops exhibited the following descending order: Roots> Shoots> Grain. Liu *et al*. (2003a) observed the mean Pb concentration in the roots, stems and leaves were 1216, 179 and 62 times higher than that in grains at ripening stage. They also added that Pb tolerance in crops is variety dependent. In contrast, Yang *et al*. (2000) reported that the tolerant rice varieties ameliorated Pb toxicity due to the release of oxalate. Likewise, Zhang *et al.* (1991) reported that the heavy metal availability can also be directly affected by plant itself. On the other hand, Pb concentration in the straw of BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45 was also found below the toxic limit as stated by Sauerbeck (1982), while in BR- 15 variety, it was found above the toxic limit, which suggested that the variety was significantly affected by Pb treatment. According to Sauerbeck (1982), the toxic concentration of Pb in the straw of rice ranged from 10 - 15 mg/kg. And, it was observed that the maximum Pb was remained in the roots of all rice plants. The results were in accordance with Sharma and Dubey (2005). They revealed that Pb concentration in various plant organs tends to decrease in the following order: Root > leaves > stem > inflorescence > seeds, but this order could vary with plant species (Antosiewicz, 1992). Jones *et al*. (1973) confirmed that plant roots restrict Pb movement in to shoots.

Likewise, Kumar *et al*. (1995) also revealed that bulk of the Pb taken up by plants remained in the roots. Sharma and Dubey (2005) gave some reasons for maximum concentration of Pb in the roots, which was due to the compartmentalization of Pb in the root vacuoles, detoxification including sequestration of Pb in the vacoule, phytochelation synthesis and binding to glutathione and amino acids, synthesis of osmolytes and activation of antioxidant

defense system. Sharma and Dubey (2005) further added that the limited transport of Pb from roots to other organs was due to the barrier of the root endodermis. Lane and Martin (1977) also agreed with the statement.

On the other hand, Jones *et al*. (1973) and Verma and Dubey (2003) also reported that Pb might move predominantly into the root apo-plast in a radical manner across the cortex and accumulate near the endodermis. The endodermis acts as a partial barrier to the movement of Pb between the root and shoot. This might in part account for the higher accumulation of Pb in roots as compared to shoots. Morel *et al*. (1986) revealed that binding of Pb to the carboxyl group of mucilage uronic acids also restricts uptake of Pb into the roots. Then again, Chino (1981) reported the following toxic levels for Pb: 50 to 2000 in tops and 300 to 3000 ppm in roots in rice crops. Horak (1996) reported a very narrow (0.003 to 0.05) transfer co-efficient of Pb from soil to plants.

4.2.4 Growth, Yield, Mineral Nutrition and Cd Concentration of Five Different Rice Varieties as Affected by Applied Cd (7 mg/kg soil) (Experiment- 2b)

4.2.4.1 *Fresh weight, dry yield and grain yield*

The growth and physical appearance of 60 days old five different rice varieties as affected by 7 mg/kg Cd over control have been depicted in Plate- 16. The mean values of fresh and dry weight and grain yield (g/pot) of five different high yielding rice varieties (BR- 15, BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45) as affected by 7 mg/kg applied Cd are presented in Table- 4.12 and Figure- 4.21. The test of significance of fresh weight, dry weight and grain yield (g/pot) of five different rice varieties was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But, in paired samples T- test, the fresh weight, dry weight and grain yield (g/pot) of BR- 15, BR- 19, Brridhan- 29 and Brridhan- 45 were found insignificant over control. On the other hand, the fresh weight of V1 variety was found highly significant (1% level), while the dry weight and grain weight were found significant at 5% level over control (Appen.Table- 21).

Plate- 16: The growth and physical appearance of five different rice varieties as affected by Cd (7 mg/kg soil) treatment over control

The fresh weight of different rice varieties under study ranged from 140.50 to 185.70 g/pot. The highest fresh weight was obtained in Brridhan- 29 (185.70 g/pot) rice and the lowest was obtained in BR- 16 (140.50 g/pot) rice. Fresh weight of V2, V3, V4 and V5 rice varieties were statistically similar. On the other hand, V2 and V5 and V2 and V3 rice varieties were significantly different from each other. Conversely, V1 rice variety was significantly different from V2, V3, V4 and V5 rice varieties. The percent reduction of the fresh weight ranged from 1.59 to 9.67% over control (Appen.Table- 21 and Figure- 4.21). The percentage fresh weight reduction exhibited the following descending order: V1 (BR-16) (9.67%)> V3 (BR-19) (4.34%)> V2 (BR-15) (4.17%)> V4 (Brridhan-45) (3.34%)> V5 (Brridhan-29) (1.59%). The highest fresh weight reduction was found in BR- 16 and the lowest was obtained in Brridhan- 29 rice variety over control.

The dry weight of five different rice varieties ranged from 29.74 to 40.14 g/pot. The highest dry weight was obtained in Brridhan- 29 (40.14 g/pot) rice and the lowest was obtained in BR- 16 (29.74 g/pot) rice variety. In fact, dry weight of V3, V4 and V5 rice varieties were statistically similar, whereas a significant difference was found between V4 and V5.

Table– 4.12: Fresh weight, dry weight and grain yield (g/ pot) of five different rice varieties as affected by applied Cd (7 mg/kg soil)

Rice Varieties		Fresh weight (g/pot)	Dry weight (g/pot)	Grain weight (g/pot)
Denotations	Name			
V1	BR-16	140.50 d	29.74 d	48.28 d
V2	BR-15	161.00 c	35.02 c	62.45 c
V3	BR-19	176.70 ab	38.90 ab	73.83 a
V4	Brridhan-45	171.30 bc	37.20 b	69.23 b
V5	Brridhan-29	185.70 a	40.14 a	77.05 a
CV	-	2.48%	2.01%	2.31%

Mean values with the same letter in the same column are not significantly different (p=0.05)
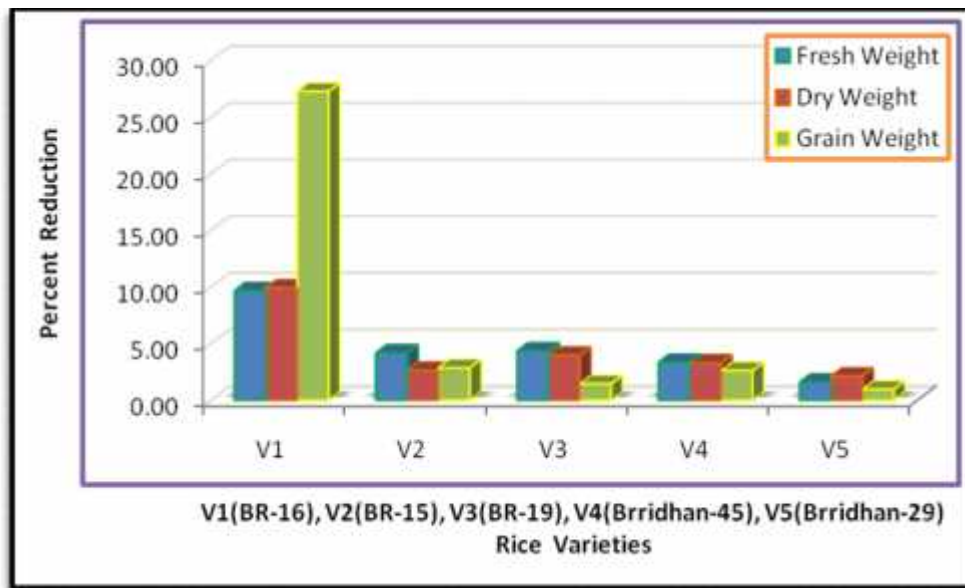
Figure- 4.21: Percent reduction of fresh weight, dry weight and grain yield of five varieties of rice as affected by applied Cd (7 mg/kg soil) Cd over control

On the other hand, V1 and V2 varieties were significantly different from each other and also from V3, V4 and V5 rice varieties. The percent reduction of dry weight ranged from 2.14 to 9.63% (Appen.Table- 21 and Figure- 4.21). The highest dry weight reduction was found in BR- 16 (9.63%) and the lowest was found in Brridhan- 29 (2.14%) rice variety over control. Then again, the percent dry weight reduction of five rice varieties showed the following order: V1 (BR-16) (9.63%) > V3 (BR- 19) (3.99%) > V4 (Brridhan-45) (3.29%) > V2 (BR-15) (2.64%) >V5 (Brridhan- 29) (2.14%).

The grain yield of five different rice varieties under study ranged from 48.28 to 77.07 g/pot. The highest grain weight was obtained in Brridhan- 29 (77.05 g/pot), followed by BR- 19 (73.83 g/pot), Brridhan- 45 (69.23 g/pot) and the lowest was obtained in BR- 16 (48.28 g/pot) rice variety. As a matter of fact, the grain weight of V3 and V5 rice varieties were statistically similar, whereas a significant difference was found among V1, V2 and V4 rice varieties, and also V3 and V5 rice varieties. The percent grain yield reduction ranged from 0.98 to 27.26%

(Appen.Table- 21 and Figure- 4.21). The highest reduction of grain weight was obtained in BR- 16 and the lowest was found in Brridhan- 29 rice variety as compared with that of control. On the other hand, the percent reduction of grain yield exhibited the following descending order: V1 (BR-16) (27.26%) > V2 (BR-15) (2.87%) > V4 (Brridhan-45) (2.62%) > V3 (BR-19) (1.46%) > V5 (Brridhan-29) (0.96%).

The above results showed that the fresh weight, dry weight and grain yield of most of the rice varieties under study were found different from each other. It might be due to the varietal difference and the yielding abilities of five different cultivars of rice. The effects of Cd on the growth and the reduction of fresh weight, dry weight and grain yield of five different rice varieties varied among them. But, a highly significant reduction of fresh weight, dry weight and grain yield was recorded in BR- 16 rice variety over control. It might be due to the fact that Cd tolerance and susceptibility to rice is variety dependent. Wu *et al*. (1999), Liu *et al*. (2003b) and He *et al*. (2006) reported that species and cultivars displayed marked differences in Cd tolerance in rice. Likewise, Bingham *et al*. (1980) recommended that the effects of Cd on the yield of rice, dry matter production or growth and development of rice were variety dependent. On the other hand, Zhang *et al*. (2002) found Cd tolerance in wheat and Metwally *et al*. (2005) found it in pea. Gupta and Potalia (1989) found that Cd depressed grain and straw yield of wheat. Bingham and Page (1975) reported that Cd reduced the growth of crops. Then again, Chino (1981) and Foroughi (1975) revealed that excess Cd in rice usually depressed the number of tillers and root growth severely. On the contrary, Wahid *et al*. (2010) observed that Cd is a critical factor affecting plant growth and toxic to most plants in trace amounts, while other plants show varying tendencies to grow under relatively high Cd levels.

4.2.4.2 *Nitrogen contents in grain, straw and roots*

The mean values of N concentrations in grain, straw and roots of five different varieties of rice as affected by 7 mg/kg applied Cd are presented in Appen.Table- 22 and in Figure- 4.22. The test of significance of N concentration in grain, straw and roots of the rice varieties under study was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But, in paired samples T- test, N content in the grains and straw of BR- 16 variety was found significant at 5% level, while the content in roots was found significant at 1% level over control. On the other hand, N content in the grains, straw and roots of four other varieties was found insignificant over control (Appen.Table- 24).

Nitrogen contents in grains of rice varieties under investigation ranged from 1.40 to 1.80%. The highest concentration was found in the grains BR- 19 rice (1.80%), followed by Brridhan- 29 (1.63%) and the lowest was found in BR- 16 (1.40%) rice variety. In fact, N content in the grains of V2 and V4 varieties were found statistically similar. On the other hand, V1, V3 and V5 rice varieties were significantly different from each other and also from V2 and V4 rice varieties. Nitrogen contents in the straw of different varieties of rice ranged

from 1.11 to 1.34%. The highest concentration was found in the grains of BR- 19 (1.34%), followed by Brridhan- 29 (1.28%) and the lowest was found in BR- 16 (1.11%) rice variety. Actually, N contents in the straw of V2 and V4 varieties were found statistically similar. On the contrary, V1, V3 and V5 varieties were significantly different from each other and also from V2 and V4 rice varieties. Like grains and straw, N contents in the roots of five different varieties of rice ranged from 0.60 to 0.84%. The highest concentration was found in the roots of BR- 19 (0.84%), followed by Brridhan- 45 (0.80%) and the lowest was found in BR- 16 (0.60%) rice variety. Moreover, N content in the roots of V1, V2, V3, V4 and V5 varieties varied significantly among them.

Figure- 4.22: N concentrations in grains, straw and roots of five different varieties of rice as affected by applied Cd (7 mg/kg soil)

Among the rice varieties, N content in grains, straw and roots of BR- 19 rice variety was found the highest and in BR- 16 variety, it was found the lowest. Then again, a slight and insignificant reduction of N concentration was found in the grains, straw and roots of BR- 15, BR- 19, BR- 45 and BR- 29 rice variety, whereas a significant reduction was observed in BR-16 variety over control. It might be due to the variation in capacity to Cd tolerance. Wu *et al*. (2004) and He *et al*. (2006) revealed that species and cultivars displayed marked differences for Cd tolerance in rice. On the other hand, N concentration in grains, straw and roots of all test rice crop varieties varied among the cultivars. Similar findings were also reported by several researchers (Jiang, 2006; Karim *et al*., 2012; Chatzistathis *et al*., 2012). Then again, Cunningham (1977) reported that Cd restricted the transfer of N from roots to shoots. Similarly, Iwai *et al*. (1975) observed a depressive effect on N uptake in plants in the higher concentration of Cd. Similar findings were also reported by Vijayarengan (2012). He observed a decrease in N content in the leaves of rice, which might be due to the presence of higher amount of Cd in soils.

4.2.4.3 *Phosphorus contents in grain, straw and roots*

The average P content in grain, straw and roots of the rice varieties under study as affected by 7 mg/kg applied Cd are presented in Appen.Table- 22 and Figure- 4.23. The test of significance of P concentration in grain, straw and roots of the rice varieties under study was computed by Duncan's Multiple Range Test (DMRT) and it was found significant at 1% level. But, in paired samples T- test, P content in grains and roots of BR- 15 rice variety was found significant at 5 % level, while in the straw, it was found significant at 1% level over control. On the other hand, P contents in the grains, straw and roots of four other varieties of rice (BR- 16, BR- 19, Brridhan- 29 and Brridhan- 45) were found insignificant over control (Appen.Table- 24).

Phosphorus content in the grains of the five rice varieties under investigation ranged from 0.28 to 0.37%. The highest concentration was found in BR- 19 (0.37%), followed by Brridhan- 29 (0.33%) and the lowest was found in BR- 16 (0.28%) rice variety. In fact, P contents in the grains of V2, V4 and V5 rice varieties were found statistically similar, whereas V4 and V5 rice varieties were significantly different from each other. On the other hand, V1 and V3 rice varieties were significantly different from each other and also from V2, V4 and V5.
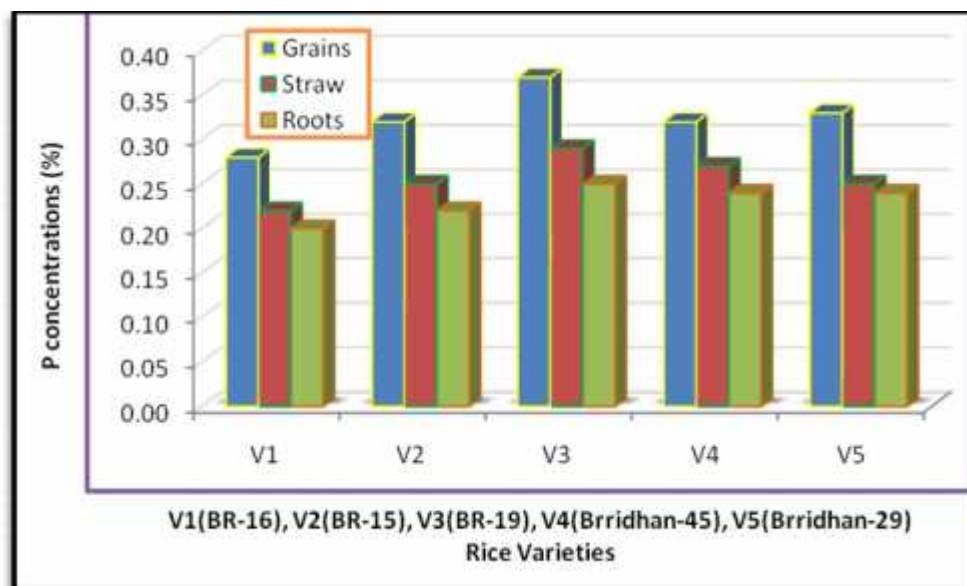
Figure- 4.23: P concentrations in grains, straw and roots of five different varieties of rice as affected by applied Cd (7 mg/kg soil)

Like grains, P contents in the straw of the rice varieties ranged from 0.22 to 0.29%. The highest concentration was found in BR- 19 (0.29%), followed by Brridhan- 45 (0.27%) and the lowest was found in BR- 16 (0.22%) rice variety. As a matter of fact, P content in the straw of V2 and V5 varieties was statistically similar. Conversely, the contents in V1, V3 and V4 varieties were found significantly different from each other and also from V2 and V5 rice varieties. Like grains and straw, P contents in the roots of rice crops under investigation

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ranged from 0.20 to 0.25%. The highest concentration was found in BR- 19 (0.25%) and the lowest was found in BR- 16 (0.20%) rice variety. As a matter of fact, P contents in the roots of V4 and V5 rice varieties were found statistically similar. On the other hand, the contents in the roots of V1, V2 and V3 rice varieties were significantly different from each other and also from V4 and V5 rice varieties.

Among the rice varieties, the highest P concentration was found in the grains, straw and roots of BR- 19 rice variety, whereas the lowest was found in the grains, straw and roots of BR- 16 rice variety. Furthermore, a significant reduction of P concentration was found in the grains, straw and roots of BR- 16 rice variety over control. On the other hand, a variation in P concentration was found among all the five rice varieties. Many researchers (Baliger *et al.*, 2001; Aziz *et al.*, 2011a; Yang *et al.*, 2011) agreed with the similar finding. Liu *et al.* (2003b) and He *et al.* (2006) observed marked differences in Cd tolerance in different rice varieties. So, the effects of Cd on P in rice might vary. On the contrary, Krupa *et al.* (1999) reported that P contents in the leaves of rye reduced by the presence of Cd, whereas Vijayarengan (2012) found it in the leaves of rice plants. Similarly, Das *et al.* (1997) reported that Cd had been shown to interfere with the uptake, transport and use of P and water by plants.

4.2.4.4 *Potassium contents in grain, straw and roots*

The mean values of K contents in the grains, straw and roots of rice varieties under study as affected by 7 mg/kg applied Cd are presented in Appen.Table- 22 and Figure- 4.24. K content in the grains, straw and roots of rice crops under study was found highly significant (1% level). But in paired samples T- test, K concentration in the grains, straw and roots of BR- 16 rice variety was found significant at 5% level over control. On the other hand, K concentration in the grains, straw and roots of other four rice varieties was found insignificant over control (Appen.Table- 25).

Potassium concentration in the grains of the test crops under study ranged from 0.72 to 0.97%. The highest concentration was found in BR- 19 (0.97%) and the lowest was found in BR- 16 (0.72%) rice variety. In fact, K concentrations in the grains of V1, V2, V3, V4 and V5 rice varieties were found significantly different from each other. Potassium concentration in the straw of rice crops ranged from 1.64 to 1.84%. The highest concentration was found in Brridhan- 29 (1.84%), followed by BR- 19 (1.79%) and the lowest was found in BR- 16 (1.64%) rice variety. As a matter of fact, K concentration in the straw of V1, V2, V3, V4 and V5 were found statistically similar. On the other hand, a significant difference was found between V1 and V3, V1 and V5 and V2 and V5 rice varieties. Like grain and straw, K contents in the roots of rice crops under investigation ranged from 0.41 to 0.52%. The highest concentration was found in Brridhan- 29 (0.52%), followed by BR- 19 (0.48%) and the lowest was found in Brridhan- 45 (0.41%) rice variety. However, K concentrations in the roots of V1, V2, V3, V4 and V5 varieties were found statistically similar. Oppositely, K in the roots of V4 and V5 varieties were found significantly different from each other.
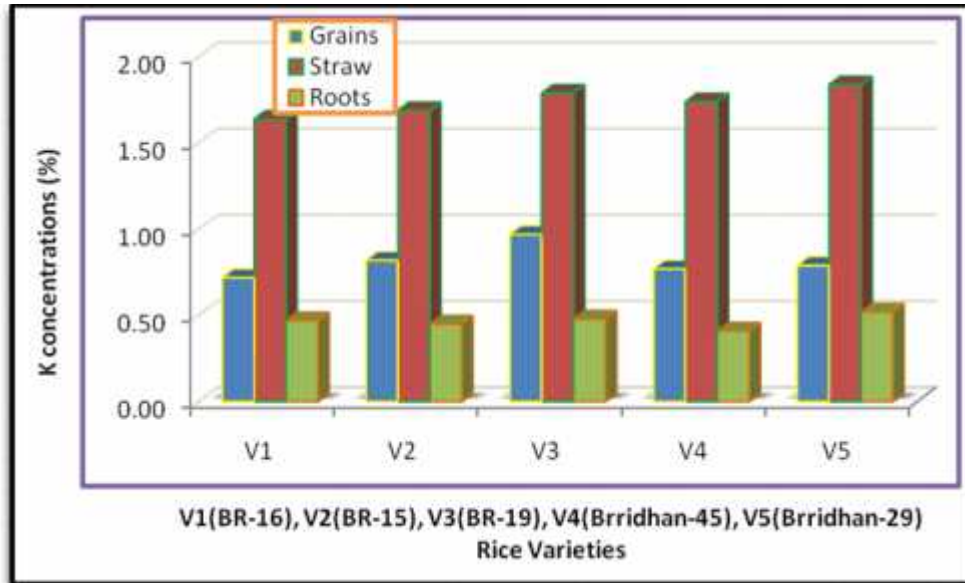
**Figure- 4.24: K concentrations in grains, straw and roots of five different varieties
of rice as affected by applied Cd (7 mg/kg soil)**

The highest K content was found in the grains of BR- 19 rice variety and in the straw and roots of Brridhan- 29 rice variety, whereas the lowest was found in the grains and straw of BR- 16 rice variety and in the roots of Brridhan- 45 rice variety. Besides, a variation in K contents was found among different rice varieties. It might be due to the variation in the potassium absorption capacity by different rice cultivars. Baligar *et al*. (2001) and Karim *et al*. (2012) reported that the nutrient utilization efficiency of difference cultivars varied within the same plant species. When compared with control, a slight reduction of K concentration was found in grains, straw and roots of all rice cultivars except BR-16, whereas a significant reduction of K content was found in grains, straw and roots of BR- 16 rice variety over control. It was evident that cultivars displayed marked differences for Cd tolerance in rice as stated by Wu *et al*. (2004) and He *et al*. (2006). On the other hand, Das *et al*. (1997) and Vijayarengan (2012) found an antagonistic effect between Cd and K, and a gradual decline of K with respect to the rise in the level of Cd.

4.2.4.5 *Calcium contents in grains, straw and roots*

The mean Ca concentrations in the grains, straw and roots of the rice varieties under study as affected by 7 mg/kg applied Cd have been presented in Appen.Table- 23 and Figure- 4.25. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But in paired samples T- test, Ca content in the grains of BR-16 rice variety was found significant at 5 % level, whereas in the straw and roots, it was found highly significant (1% level) over control. On the other hand, Ca content in four other varieties of rice was found insignificant over control (Appen.Table- 25).

Calcium concentrations in the grains of test rice varieties ranged from 0.66 to 0.86%. The highest concentration was found in BR- 15 (0.86%), followed by BR- 19 (0.79%) and the

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lowest was found in Brridhan- 45 (0.66%). As a matter of fact, Ca concentration in the grains of V1, V2, V3, V4 and V5 varieties were found statistically similar.
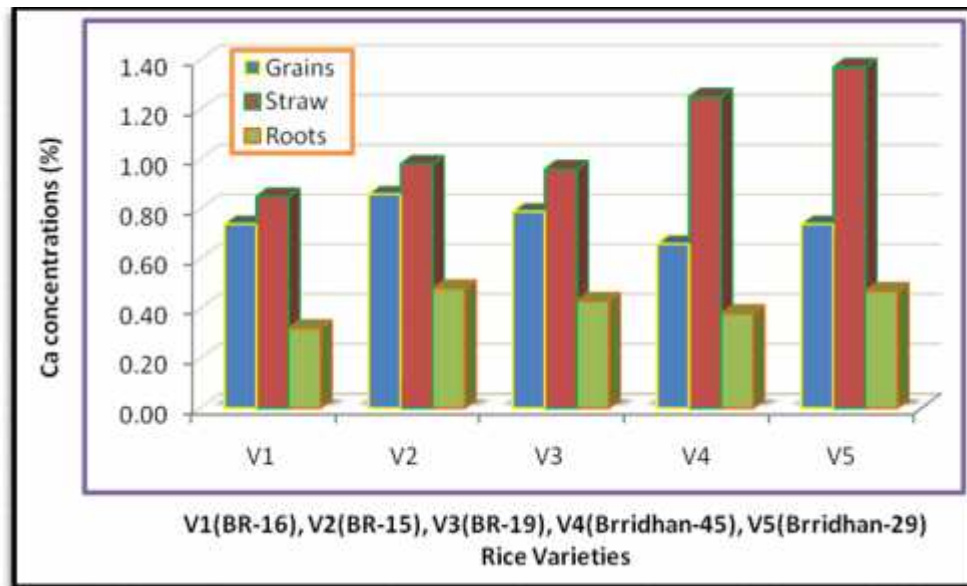
Figure- 4.25: Ca concentrations in grains, straw and roots of five different varieties of rice as affected by applied Cd (7 mg/kg soil)

In contrast, Ca in the grains of V2 variety was significantly different from V1, V4 and V5 and V2 was significantly different from V4 rice variety. Calcium content in the straw of the rice varieties under study ranged from 0.85 to 1.37%. The highest content was found in Brridhan- 29 (1.37%), followed by Brridhan- 45 (1.25%) and the lowest was found in BR- 16 (0.85%) rice variety. But, Ca in the straw of V2 and V3 varieties was found statistically similar. On the other hand, the contents in the straw of V1, V4 and V5 varieties were found significantly different from each other and also from V2 and V3 rice varieties. Like grains and straw, the mean Ca contents in the roots of rice crops under investigation ranged from 0.32 to 0.48%. The highest concentration was found in BR- 15 (0.48%), followed by Brridhan- 29 (0.47%) and the lowest was found in BR- 16 (0.32%) rice variety. In fact, Ca contents in the roots of V1, V2, V3, V4 and V5 rice varieties were found significantly different from each other. On the other hand, when compared with control, a minor reduction of Ca content was found in the grains, straw and roots of BR- 15, BR- 19, BR- 29 and BR- 45 rice varieties, while a significant reduction was observed in the grains, straw and roots of BR- 16 rice variety over control (Appen.Table- 25).

It was evident that the highest Ca content was found in the grains and roots of BR- 15 rice varieties and in the straw of BR- 29 rice, while the lowest Ca content was found in the grains of BR- 45 rice as well as in the straw and roots of BR- 16 rice variety. The results were in agreement with Wu *et al*. (2004) and He *et al*. (2006). They revealed that species and cultivars displayed marked differences in Cd tolerance in rice. On the other hand, Karim *et al*. (2012) and Chatzistathis *et al*. (2012) found a wide variation concerning nutrient utilization

efficiency among genotypes (cultivars) of the same plant. Vijayarengan (2012) explained that the uptake of Ca in rice decreased due to the antagonistic action of Ca with Cd. Similar findings were also reported by Bonnet *et al*. (2000) and Stoyanova and Doncheva (2002) in the case of Zn.

4.2.4.6 *Magnesium contents in grain, straw and roots*

The mean Mg concentrations in grains, straw and roots of the rice varieties under investigation as affected by 7 mg/kg applied Cd have been presented in Appen.Table- 23 and Figure- 4.26. The test of significance of the Mg content in grains, straw and roots of different rice varieties was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But in paired samples T- test, Mg content in the grains of BR- 16 rice was found significant at 5% level, whereas in straw and roots, it was found highly significant (1% level) over control. On the other hand, Mg content in grains, straw and roots of BR- 15, BR- 19, BR- 29 and BR- 45 rice varieties was found insignificant over control (Appen.Table- 26).

Magnesium concentration in the grains of five different varieties of rice under study ranged from 0.47 to 0.66%. The highest content was found in BR- 15 (0.66%), followed by BR- 19 (0.60%) and the lowest was found in Brridhan- 45 (0.47%) rice variety. In fact, Mg concentration in grains of V1, V2, V3, V4 and V5 rice varieties was found significantly different from each other. Similarly, Mg content in the straw of the rice varieties under investigation ranged from 0.50 to 0.73%. The highest concentration was found in Brridhan- 29 (0.73%), followed by Brridhan- 45 (0.71%) and the lowest was found in BR- 16 (0.50%) rice variety. Furthermore, among V1, V2, V3, V4 and V5 varieties of rice, a significant difference was found in Mg contents in the straw.
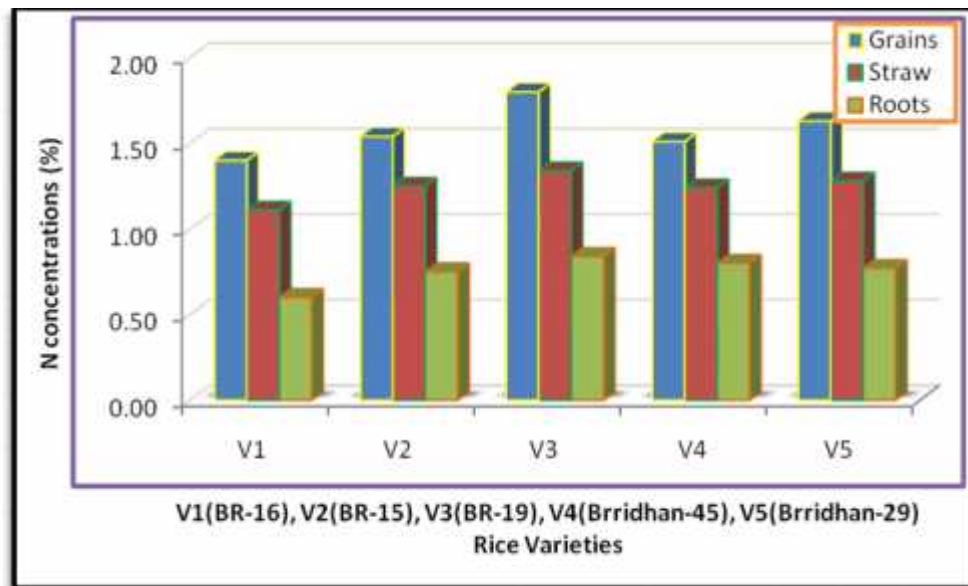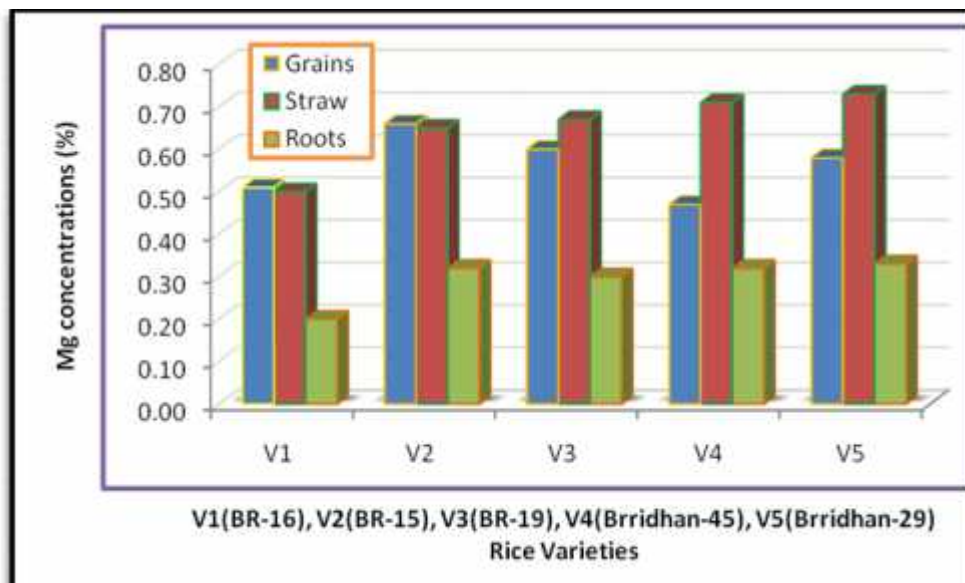

Figure- 4.26: Mg concentrations in grains, straw and roots of five different varieties of rice as affected by applied Cd (7 mg/kg soil)

Like grains and straw, Mg contents in the roots of test rice crop varieties ranged from 0.20 to 0.33%. The highest was found in Brridhan- 29 (0.33%), followed by Brridhan- 45 (0.32%) and BR- 15 (0.32%) and the lowest was found in BR- 16 (0.20%) rice variety. In fact, Mg content in the roots of V2 and V4 varieties was found statistically similar. On the other hand, Mg in the roots of V1, V3 and V5 varieties were found significantly different from each other and also from V2 and V4 rice varieties.

It was obvious that among the five varieties of rice, the highest Mg content was found in the grains of BR- 15 rice variety as well as in the straw and roots of Brridhan- 29 rice, while the lowest content was found in the grains of Brridhan- 45 rice and the straw and roots of BR- 16 rice variety. The results were in accordance with Baliger *et al.* (2001), Jiang (2006) and Chatzistathis *et al.* (2012). They found a wide variation regarding nutrient utilization competence among the cultivars of the same plant species. Then again, a reducing trend of Mg content was observed in all the rice crops under study, whereas a significant reduction was observed in the grains, straw and roots of BR- 16 rice variety over control. Liu *et al.* (2003b) and He *et al.* (2006) revealed that the species and cultivars of rice displayed noticeable differences for Cd tolerance. On the other hand, an antagonistic effect of Cd on Mg uptake in plants was observed by Iwai *et al.* (1975) and Cunningham (1977). Likewise, Grussarsson (1994) also found an antagonistic effect of Cd in the uptake of Ca in rice plants. Conversely, Jasiewiz and Antonkiewicz (1999) reported higher Mg in the top of the *Amaranthus hypochondriacus* than in the roots in heavy metal contaminated soil.

4.2.4.7 *Cd concentrations in grains, straw and roots*

The mean values of Cd concentrations in the grains, straw and roots of the rice varieties under study as affected by 7 mg/kg applied Cd are presented in Table- 4.13. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But, in paired samples T- test, Cd content in the grains, straw and roots of test crops was also found highly significant (1% level) over control (Appen.Table- 27).

Cadmium concentrations in the grains of five different rice varieties under investigation ranged from 0.02 to 1.10 mg/kg. The lowest concentration was found in the grains of Brridhan- 29 (0.02 mg/kg) and BR -19 (0.024 mg/kg), followed by Brridhan- 45 (0.03 mg/kg) and the highest was found in the grains of BR- 16 (1.10 mg/kg) rice. Cd concentrations in the grains of the rice varieties exhibited the following descending order: V1 (BR- 16) (1.10 mg/kg)> V4 (BR- 15) (0.05 mg/kg)> V2 (Brridhan- 45) (0.03 mg/kg)> V3 (BR- 19) (0.024 mg/kg> V5 (Brridhan- 29) (0.02 mg/kg). In fact, Cd concentrations in the grains of V2, V3, V4 and V5 varieties were statistically similar, whereas V1 variety was significantly different from V2, V3, V4 and V5 rice varieties.

Like grains, Cd concentrations in the straw of test rice varieties ranged from 3.79 to 14.48 mg/kg. The lowest was found in the straw of BR- 19 (3.79 mg/kg), followed by Brridhan- 29

(4.02 mg/kg) and Brridhan- 45 (4.80 mg/kg) and the highest concentration was found in the straw of BR- 16 (14.48 mg/kg) rice.

Table- 4.13: Concentrations and the transfer co-efficients of Cd in the grains, straw and roots of five different rice varieties as affected by applied Cd (7 mg/kg soil)

Rice Varieties		Cd Concentrations					
		Grains		Straw		Roots	
Denotation	Name	Conc. (mg/kg)	TC	Conc. (mg/kg)	TC	Conc. (mg/kg)	TC
V1	BR-16	1.10 a C	0.157	14.48 a B	2.06	35.00 c A	5.0
V2	BR-15	0.05 b C	0.019	7.85 b B	1.12	37.67 bc A	5.38
V3	BR-19	0.024 b C	0.017	4.80 c B	0.69	42.67 b A	6.09
V4	Brridhan-45	0.03 b C	0.021	4.02 c B	0.57	44.67 b A	6.38
V5	Brridhan-29	0.02 b C	0.017	3.79 c B	0.54	66.33 a A	9.48
CV	-	18.34%	-	3.27%	-	5.46%	-

Mean values with the same letter in the same row (capital letters) and the same column (small letters) are not significantly different (p=0.05)

But, Cd content in the straw of V3, V4 and V5 rice varieties was found statistically similar. On the other hand, the content in the straw of V1 and V2 was significantly different from each other and also from V3, V4 and V5 rice varieties. Then again, Cd concentration in the straw of rice varieties showed the following descending order: V1 (BR- 16) (14.48 mg/kg)> V2 (BR- 15) (7.85 mg/kg)> V3 (BR- 19) (4.80 mg/kg)> V5 (Brridhan- 45) (4.02 mg/kg)> V3 (Brridhan- 29) (3.79 mg/kg).

 Like grains and straw, Cd concentrations in the roots of rice varieties under study varied from 35.0 to 66.33 mg/kg. The lowest Cd concentration was found in the roots of BR- 16 (35 mg/kg), followed by BR- 15 (37.67 mg/kg) and BR- 19 (42.67 mg/kg) and the highest was found in the roots of Brridhan- 29 (66.33 mg/kg) rice. As a matter of fact, Cd concentration in the roots of V1, V2, V3 and V4 rice varieties was found statistically similar, while V1 was significantly different from V3 and V4 varieties. Conversely, V5 was significantly different from V1, V2, V3 and V4 varieties. In addition, Cd concentration in the roots of five rice varieties showed the following descending order: V5 (Brridhan- 29) (66.33 mg/kg)> V4 (Brridhan- 45) (44.67 mg/kg)> V3 (BR- 19) (42.68 mg/kg)> V2 (BR- 15) (37.66 mg/kg)> V1 (BR- 16) (35.00 mg/kg). The transfer co-efficients of Cd in grains, straw and roots of five different varieties ranged from 0.017 to 0.157, 0.54 to 2.06 and 5.0 to 9.48, respectively (Table- 4.13). On the other hand, Cd concentrations in different parts of all five rice varieties exhibited the following descending order: Roots> straw> grains.

It was observed from the above results that the contents of Cd in the grains of BR- 15, BR- 19, Brridhan- 29 and Brridhan- 45 rice varieties were very low and within the tolerable limit (< 0.2 mg/kg) as described by FAO/WHO (2001) and Shakerian *et al*. (2013), whereas in BR- 16 rice variety, it was found substantially high and above the tolerable limit. The highest Cd concentration was also found in the straw of BR- 16 rice variety, but the lowest was found in

the roots of the same variety. Conversely, Cd concentration in the roots of Brridhan- 29 rice variety was found the highest, though in the straw and roots, it was found the lowest. On the other hand, Cd concentration in the straw of BR- 16 rice variety was found above the toxic level, while the concentrations in BR- 15, BR- 19, Brridhan- 29 and Brridhan- 45 was found within the tolerable limit (5- 10 mg/kg) as described by Sauerbeck (1982). And, among the different parts of five rice varieties, Cd concentration decreased in the following descending order: Roots > straw > grains. On the other hand, Blum (1997) reported that in general, the content of Cd in different plants declined in the following order: roots > stems> leaves > fruit > seed.

So, it was evident that Cd sequestered and compartmentalized into the root vacuoles of all five varieties of rice, which might make a barrier to transfer Cd from roots to the above ground parts of rice. The same inference might be applicable in the case of BR- 15, BR- 19, Brridhan- 29 and Brridhan- 45 rice varieties. But, by losing the function of allelic gene, the roots of BR- 16 rice variety transferred higher amounts of Cd from roots to straw and grains as described by Ueno (2010). According to his statement, the allelic gene in the roots of rice act as firewall, when cultivars of rice lose its function accumulate higher amount of Cd. This might be the cause of the highest Cd accumulation in the straw and grains of BR- 16 rice variety as compared with other varieties. On the other hand, Nishizono *et al*. (1989) reported that the cell wall of the root could act as a first barrier against Cd stress in immobilizing excess of Cd. And, it is important to notice that rice cultivars differed significantly in Cd uptake and accumulation (Morishita *et al*., 1987, Shah *et al*., 2001). Similarly, Penner *et al*. (1995), Athur *et al*. (2000) and Zhang *et al*. (2002) reported that the uptake of Cd can vary greatly among plant species and also among cultivars within a species. The redox potential in the rhizosphere and uptake of Cd by rice is significantly affected by the root oxidation ability of rice (Liu *et al*., 2000). It is also important to mention that the chemical and biological metal binding capacity of soil can reduce the uptake of Cd (Costa and Morel, 1993; Sanita di Toppi *and* Gabbrielli, 1999; Rauser, 1999; Schat *et al*., 2002; Clemens and Simm, 2003). And, plant can synthesize many metabolites, including phytochelatins, metallothioneins and organic acids, which can bind and inactivate Cd. Leon *et al*. (2002) reported that plant as a tolerant mechanism partition Cd in various parts including roots, above ground vegetation and reproductive part. On the other hand, Iimura and Ito (1971) reported the critical Cd content in plant tissues above which growth is retarded about 10 ppm but later Chino (1981) modified the level to be 5 to 10 ppm for rice tops and 100 to 600 ppm for rice roots. It is interesting to note that Cd concentrations in rice grains differed among cultivars even when they are planted in soils with comparable soil properties and total soil Cd levels (He *et al*., 2006 and Römkens *et al*., 2009). Roots of rice excrete some organic substances to rhizosphere during the growth, and rhizosphere controls the entrance of nutrients, water and other chemicals, beneficial or harmful to plants, which was the main Cd tolerance mechanism in soil- plant systems (Dong *et al*., 2007). According to Horak (1996), the transfer co-efficient of Cd from soil to plants ranged from 0.20 to 2.0.

4.2.5 Growth, Yield, Mineral Nutrition and Pb Contents of Different Leafy Vegetable Crops and a Grass as Affected by Applied Pb (200 mg/kg soil) (Experiment- 3a)

4.2.5.1 *Fresh and dry weight*

The growth and physical appearance of 65 days old three different leafy vegetables and a Grass crop as affected by 200 mg/kg Pb have been depicted in Plate- 17. The mean values of fresh weight and dry weight of different leafy vegetables and grass as affected by 200 mg/kg applied Pb are presented in Table- 4.14. The test of significance of both fresh and dry weight was computed by Duncan's Multiple Range Test's (DMRT) at 1% level. But, in paired samples T- test, both fresh and dry weight of Spinach was found significant at 5% level, whereas Lal sak, Kalmi sak and Grass were found insignificant over control (Appen.Table- 28).
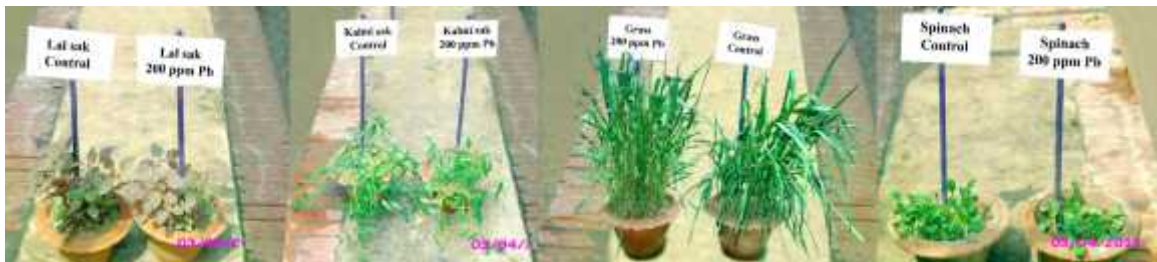
Plate- 17: The growth and physical appearance of three leafy vegetables and a grass crop as affected by Pb (200 mg/kg soil) treatments over control

Table- 4.14: Fresh and dry weight of the four different test crops under study as affected by applied Pb (200 mg/kg soil)

Crop Types		Fresh weight (g/pot)	Dry weight (g/pot)
Denotations	Names		
V1	Lal sak	32.13 c	2.88 c
V2	Kalmi sak	46.28 b	4.14 b
V3	Grass	66.02 a	10.65 a
V4	Spinach	31.71 c	2.98 c
CV	-	2.28%	2.52%

Mean values with the same letter in the same column are not significantly different (p=0.05)

The fresh weight of different test crop plants ranged from 31.71 to 66.02 g/pot. The highest fresh weight was obtained in Grass (66.02 g/pot), followed by Kalmi sak (46.28 g/pot) and the lowest was obtained in Spinach (31.71 g/pot). The fresh weight of Lal sak (V1) and Spinach (V4) was found statistically similar, while Kalmi sak (V2) and grass (V3) were significantly different from each other and also from Lal sak (V1) and Spinach (V4). The percent reduction of fresh matter production of different crop varieties ranged from 2.42 to 27.65% over control (Appen.Table- 28 and Figure- 4.27). The highest yield reduction was observed in Spinach and the lowest was in Grass (Appen.Table- 28). The decrements of fresh

weight of different vegetables and grass have shown the following order: Spinach (27.65%) > Lal sak (4.74%) > Kalmi sak (2.56%) > Grass (2.42%).
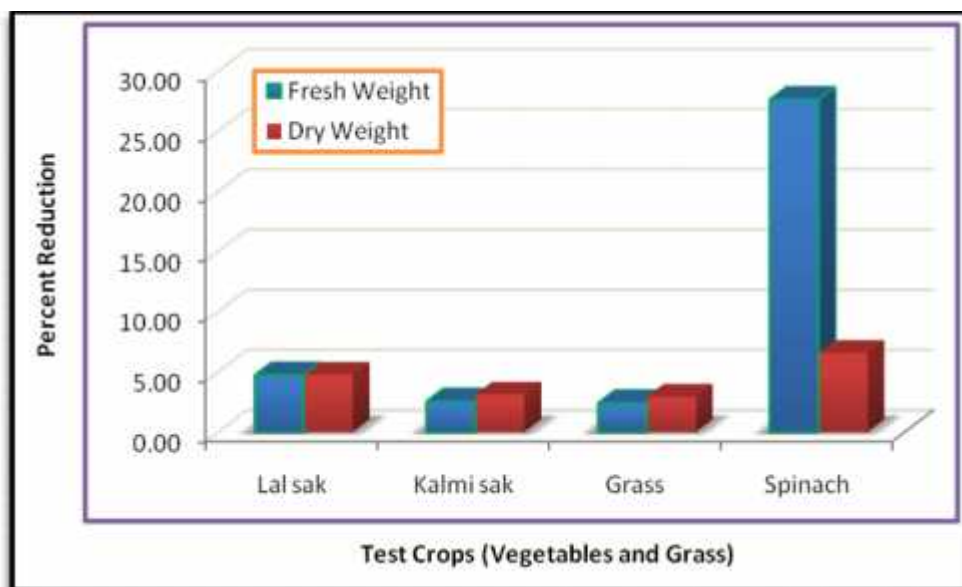
Figure- 4.27: Percent reduction of fresh weight and dry weight of four test crops under study as affected by applied Pb (200 mg/kg soil) over control

The dry weight of different crops ranged from 2.88 to 10.65 g/pot. The lowest dry weight was obtained in Lal sak (2.88 g/pot), followed by Spinach (2.98 g/pot) and Kalmi sak (4.14 g/pot) and the highest was obtained in grass (10.65 mg/kg). In fact, the dry weight of Lal sak (V1) and Spinach (V4) was found statistically similar. On the other hand, Kalmi sak (V2) and Grass (V3) were found significantly different from each other and also from Lal sak (V1) and Spinach (V4). The percent dry weight reduction of the different crops varied from 2.85 to 6.59% over control (Appen.Table- 28 and Figure- 4.27). And, the highest dry weight reduction was obtained in Spinach (6.59 %), followed by Lal sak (4.78%) and the lowest was recorded in Grass (2.85%) (Appen.Table- 28).

It was observed that the highest fresh weight (per pot) was obtained in Grass and the lowest was obtained in Spinach. On the other hand, the highest fresh weight reduction was recorded in Spinach and the lowest in Grass. It needs to mention that the fresh weight of Spinach has been significantly affected by applied (200 mg/kg) Pb over control. Like fresh weight, the highest dry weight was obtained in Grass and the lowest was obtained in Lal sak. In contrast, the highest reduction of dry weight was obtained in Spinach and the lowest was found in Grass over control. And, it was evident that crops such as Grass, Kalmi sak and Lal sak showed tolerance characteristics against 200 mg/kg Pb stress, but spinach was most susceptible to Pb.

Several researchers explained it in different ways. Khan and Frankland (1983) observed that Pb toxicity in radish resulted stunted growth of both roots and shoots. Similarly, Adriano (1986) found growth retardation of spinach due to Pb activity. Likewise, Patrick and Bisessar

(1991) observed the reduction of dry matter of onion, potatoes, cabbage and lettuce due to Pb toxicity. Kosobrukhov *et al.* (2004) also reported a considerable decrease in dry weights of different plant parts under Pb treatments. Miles *et al.* (1972) also added that excess Pb inhibited photosynthetic electron transport in isolated spinach chloroplasts, which ultimately affect the growth of plants. On the other hand, Grass was considered as metal tolerant crop. And, in this regard, Rotkittikhun *et al.* (2007) reported that some varieties of grasses that could tolerate high Pb concentration in soil ranged from 10 - 700 mg/kg and also showed a good growth performance. And, the mechanism of Pb tolerance in grass was to activate the carbohydrase activity in grass by Pb as reported by Igoshina and Kositcin (1990). Then again, Rahman *et al.* (2007) recommended Kalmi sak (*Ipomoea aquatica*) as a Pb hyper accumulator, as this vegetable accumulated appreciable quantities of metals in their tissues without significant reduction of normal growth performance.

On the other hand, Kibria *et al.* (2009) found that the shoot and root weight of *Amaranthus gangeticus* decreased by 28 and 53 % with 100 mg /kg Pb treatment, as compared to that of control. Similarly, Kopittke *et al.* (2007) found the reduction of fresh mass of cowpea (*Vigna unguiculata*) by 10% at a Pb^{2+} activity of 0.2 μM for the shoots and 0.06 μM for the roots. Likewise, Nehnevajova (2005) observed that the decrease of dry weight of two sunflower varieties cultivated in a hydroponic system spiked with Pb at 7.5 and 10 μM. In addition, Huang and Cunningham (1996) revealed that after 2 weeks of Pb exposure at 0, 5, 20, 50 and 100 μM, with increasing Pb concentration significantly decreased both shoot and root dry weight of corn and ragweed. They also reported that the shoot and root weight decreased linearly with increasing Pb concentration up to 50 μM. And, above this concentration, there was no further reduction in root growth.

4.2.5.2 *Nitrogen concentrations in straw and roots*

 The average N contents in the straw and roots of four different leafy vegetables and grass under study as affected by 200 mg/kg applied Pb are presented in Appen.Table- 29 and Figure- 4.28. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But in paired samples T- test, N content in the straw and roots of Spinach was found significant at 1% and 5% level, respectively, but N content in the straw and roots of three other crops was found insignificant over control (Appen.Table- 30).

Nitrogen contents in the straw of different leafy vegetables and grass under study varied from 2.51 to 3.50%. The highest concentration was found in the straw of Spinach (3.50%), followed by Kalmi sak (3.08%) and the lowest was found in Grass (2.51%). In fact, N content in the straw of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) differed significantly among them. Like straw, N content in the roots of different crops under study varied from 1.19 to 1.81%. The highest content was found in the roots of Kalmi sak (1.81%),

followed by Spinach (1.80%) and the lowest was found in Grass (1.19%). As a matter of fact, N content in the roots of Kalmi sak (V2) and Spinach (V4) was found statistically similar, whereas Lal sak (V1) and Grass (V3) were significantly different from each other and also from Kalmi sak (V2) and Spinach (V4).
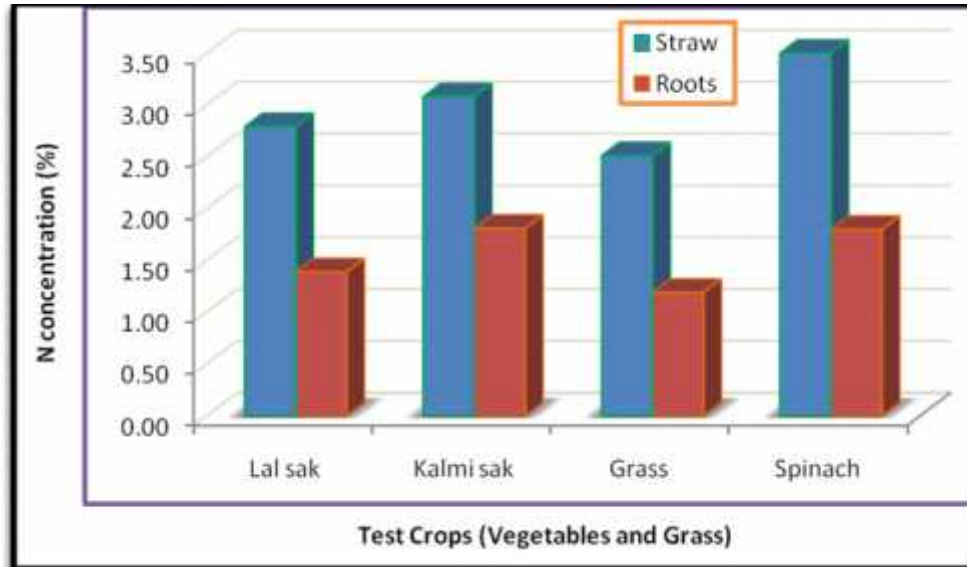
Figure- 4.28: N concentrations in straw and roots of four t test crops under study as affected by applied Pb (200 mg/kg soil) over control

On the other hand, when the treatments were compared with control, N contents in the straw and roots of Lal sak, Kalmi sak and Grass remained unaffected by Pb stress, but a significant impact was found in spinach. However, N contents in straw and roots of four different crops varied significantly among them. The results were in agreement with Chatzistathis *et al.* (2009) and Karim *et al.* (2012). They reported that nutrient accumulation efficiency varied within different cultivars of the same species. Conversely, the effect of Pb on the growth of crops is variety dependant (Liu *et al.*, 2003a). Then again, Lee and Kim (1991) and Strand *et al.* (1990) observed that Pb had an antagonistic effect on N uptake by rice plants. Likewise, Pb treatment reduced uptake of NO_3^- in *Cucumis sativus* as reported by Walker *et al.* (1997).

4.2.5.3 *Phosphorus concentrations in straw and roots*

The mean phosphorus concentrations in the straw and roots of the crops under study as affected by 200 mg/kg applied Pb are presented in Appen.Table- 29 and Figure- 4.29. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But in paired samples T- test, P concentration in the straw and roots of Spinach was found significant at 1% and 5% level, respectively, while the concentrations in the straw and roots of three other crops were found insignificant over control (Appen.Table- 30).

Phosphorus concentration in the straw of the test crops varied from 0.28 to 0.39%. The highest concentration was found in Kalmi sak (0.39%), followed by Lal sak (0.34%) and the lowest was found in the straw of Spinach (0.28%). Statistically, P concentration in the straw of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) was found significantly different from each other. Like straw, P contents in the root of four vegetables and grass ranged from 0.16 to 0.26%. The highest content was found in Kalmi sak (0.26%), followed by Lal sak (0.20%) and the lowest was found in the roots of Spinach (0.16%) and Grass (0.16%). In fact, P concentration in the roots of Grass (V3) and Spinach (V4) was found statistically similar. On the other hand, the contents in Lal sak (V1) and Kalmi sak (V2) were found significantly different from each other and also from Grass (V3) and Spinach (V4).
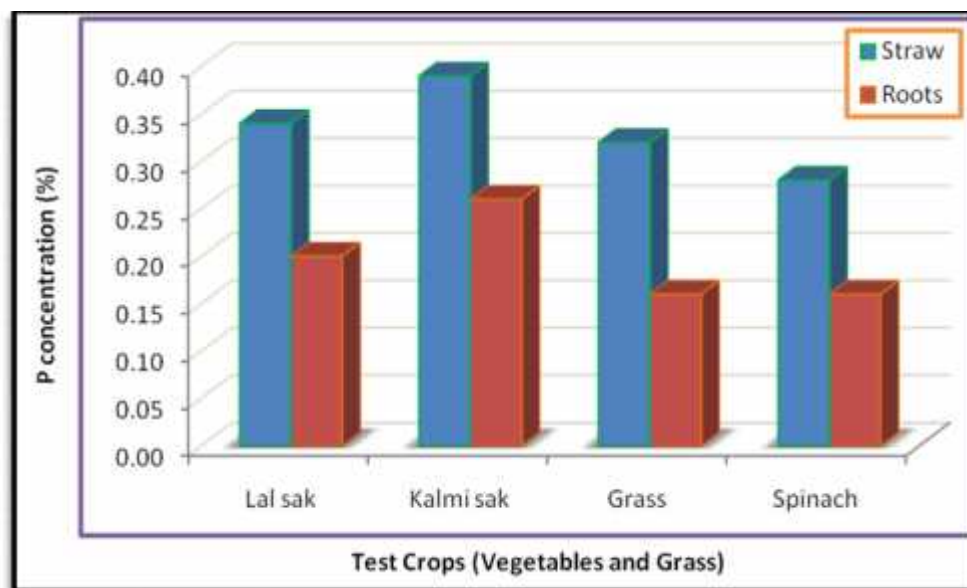
Figure- 4.29: Phosphorus concentrations in straw and roots four crops under study as affected by applied Pb (200 mg/kg soil) over control

Among the four crops, the highest P content was found in the straw and roots of Kalmi sak and the lowest was found in the straw of Spinach and roots of Spinach and Grass. Among the crops, a significant variation in P content was found. Many researchers (Baligar *et al*., 2001; Aziz *et al*., 2011a; Chatzistathis *et al*., 2012) found significant difference concerning nutrient utilization efficiency among genotypes (cultivars) of the same species. On the other hand, when P content was compared with control, a significant reduction was found both in straw and the roots of Spinach and three other crops remained unaffected. It might be due the fact that the effect of Pb on the growth of crops was species and cultivar dependent (Liu *et al*., 2003a). Then again, Paivoke (2002) found that Pb influenced the overall distribution of nutrient elements within different organs of plants. Phosphorus content was found to be negatively correlated with Pb. Similarly, Walker *et al*. (1997) found reduced uptake of P in *Zea mays* due to Pb treatment.

4.2.5.4 *Potassium concentrations in straw and roots*

The mean K concentrations in the straw and roots of different crops as affected by 200 mg/kg applied Pb are presented in Appen.Table- 29 and Figure- 4.30. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). And, in paired samples T- test, K content in the straw and roots of Spinach was found significant at 1% level and 5% level, respectively, whereas the content in the straw and roots of three other crops was found insignificant over control (Appen.Table- 30).

Potassium concentration in the straw of four different test crops ranged from 2.25 to 4.79%. The highest content was observed in the straw of Lal sak (4.79%) and the lowest was found in Grass (2.25%). As a matter of fact, a significant variation in K concentration was found among Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4). Like straw, K concentration in the roots of crops under study ranged from 1.50 to 1.88%. The highest concentration was observed in the roots of Kalmi sak (1.88%), followed by Spinach (1.78%) and the lowest was found in Lal sak (1.50%). But, K concentration in the roots of Lal sak (V1) and Grass (V3) was found statistically similar, while K content in Kalmi sak (V2) and Spinach (V4) was significantly different from each other and also from Lal sak (V1) and Grass (V3).
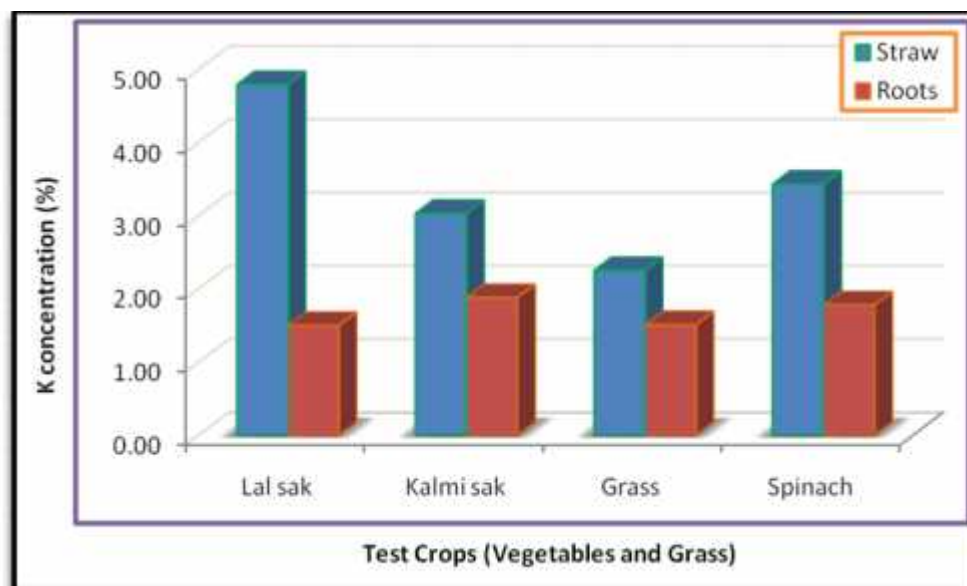
Figure- 4.30: Potassium concentrations in straw and roots of crops under study as affected by applied Pb (200 mg/kg soil)

It was evident from the above results that the highest K content was observed in straw of Lal sak and roots of Kalmi sak and the lowest was found in the straw of Grass and roots of Lal sak. Chatzistathis *et al*. (2009) and Karim *et al*. (2012) observed a variation in nutrient utilization efficiency of different species of crops. When compared with control, a significant reduction of K concentration was found in the straw and roots of Spinach, whereas a slight

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but insignificant reduction was observed in the straw of three other crops. It might be due to the fact that crop varieties displayed marked differences in Pb tolerance as described by Liu *et al*. (2003a). On the other hand, Godbold and Kettner (1991) reported that Pb physically blocks the access of many ions from absorption sites of the roots. Similar results were also reported by Khan and Khan (1983). They revealed that the different levels of Pb significantly affected K contents and uptake in tomato and eggplants. Likewise, Kim *et al*. (1986) also reported that Pb toxicity reduced K uptake by rice and Walker *et al*. (1997) found it in *Cucumis sativus*.

4.2.5.5 *Calcium concentrations in straw and roots*

The mean Ca contents in the straw and roots of test crops under study as affected by 200 mg/kg applied Pb are presented in Appen.Table- 29 and Figure- 4.31. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But in paired samples T- test, Ca concentration in straw and roots of Spinach was found significant at 1% level, while the content in the straw and roots of Lal sak, Kalmi sak and Grass was found insignificant over control (Appen.Table- 31).

Calcium concentration in the straw of crops under investigation varied from 1.27 to 1.63%. The highest value was observed in the straw of Spinach (1.63%), followed by Kalmi sak (1.38%) and the lowest was found in Lal sak (1.27%). As a matter of fact, Ca content in the straw of Lal sak (V1), Kalmi sak (V2) and Grass (V3) was found statistically similar, but Kalmi sak (V2) was significantly different from Lal sak (V1). On the other hand, Spinach (V4) was significantly different from Lal sak (V1), Kalmi sak (V2) and Grass (V3).

Figure- 4.31: Ca concentrations in straw and roots of four different crops under study as affected by applied Pb (200 mg/kg soil)

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Like straw, Ca contents in the roots of crops under study varied from 0.42 to 0.66%. The highest content was observed in the roots of Grass (0.66%), followed by Spinach (0.64%) and the lowest was found in Lal sak (0.42%). But statistically, Ca concentration in the roots of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) varied significantly among them.

It was observed that highest Ca concentration was found in the straw of Spinach and the roots of Grass and the lowest was found in the straw and roots of Lal sak. The results were in accordance with Chatzistathis *et al.* (2009) and Karim *et al.* (2012).They noticed that the nutrient utilization efficiency of different crop species was different.

On the other hand, a significant reduction of Ca concentration was found in the straw and roots of Spinach, whereas the straw and roots of Lal sak, Kalmi sak and Grass remained unaffected over control. It might be due to the variation in Pb tolerance potentials of different crops. The result was in accordance with Liu *et al.* (2003a). Then again, Godbold and Kettner (1991) reported that Pb physically blocks the access of Ca from absorption sites of the roots and Sharma and Dubey (2005) found it in the root system of rice plants. Similar findings were also reported by Lee and Kim (1991). They revealed that Pb toxicity had an antagonistic effect on Ca uptake by plants. Likewise, Walker *et al.* (1997) reported that Pb treatment reduced uptake of Ca in *Cucumis sativus.*

4.2.5.6 *Magnesium concentrations in straw and roots*

The mean Mg concentrations in the straw and roots of four different test crops under investigation as affected by 200 mg/kg applied Pb are presented in Appen.Table- 29 and Figure- 4.33. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But in paired samples T- test, Mg content in straw and roots of Spinach was found significant at 5% level, whereas the content in the straw and roots of three other crops was found insignificant over control (Appen.Table-31).

 Magnesium content in the straw of four different crops under study ranged from 0.73 to 0.90%. The highest was observed in the straw of Grass (0.90%), followed by Spinach (0.85%) and Lal sak (0.85%) and the lowest was found in Kalmi sak (0.73%). In fact, Mg content in the straw of Lal sak (V1), Grass (V3) and Spinach (V4) was found statistically similar. In contrast, the content in the straw of Kalmi sak (V2) was found significantly different from Lal sak (V1), Grass (V3) and Spinach (V4).

Like straw, the values of Mg in the roots of test crops under investigation ranged from 0.19 to 0.33%. The highest content was observed in Grass (0.33%) and the lowest was found in Kalmi sak (0.19%). As a matter of fact, Mg content in the roots of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) varied significantly among them.
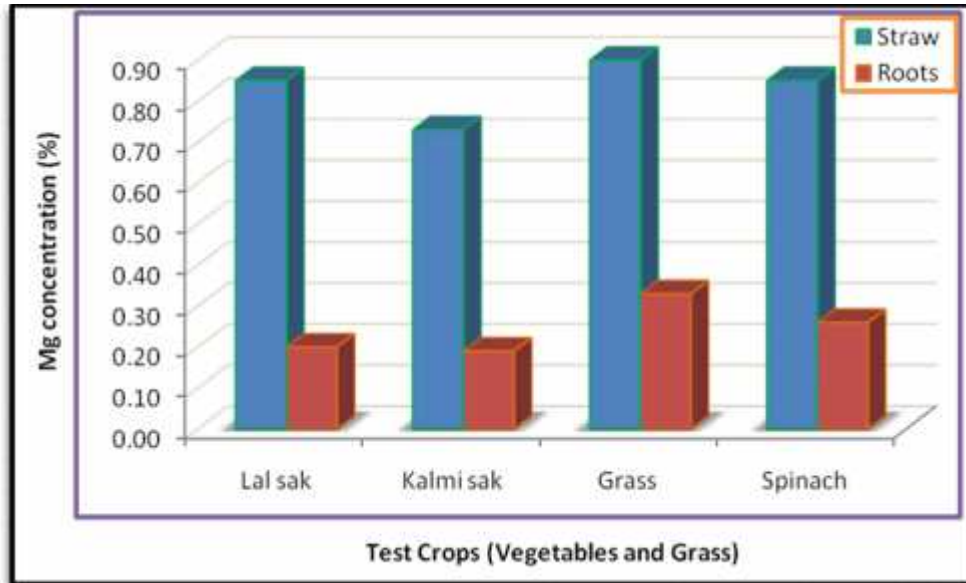
Figure- 4.32: Mg concentrations in straw and roots of four different crops under study as affected by applied Pb (200 mg/kg soil)

It was observed that the highest Mg content was found in the straw and roots of Grass and the lowest was found in the straw and roots of Kalmi sak. The results were in accordance with the findings of Aziz *et al*. (2011a) and Yang *et al*. (2011). They found a wide variation in the nutrient utilization efficiency of different species of crops.

When compared with control, a significant reduction of Mg concentration was observed in both straw and roots of spinach, while in three other crops, a slight decrement of Mg was observed. The results were in consonance with the findings of Liu *et al*. (2003a). They found an extensive variation in Pb tolerance capacity of different species of crops. On the other hand, Kim *et al*. (1986), Xian (1989) and Sharma and Dubey (2005) found an antagonistic effect of Pb on Mg as well. Similarly, Lee and Kim (1991) and Hirayama and Kobayashi (1989) also revealed an adverse effect on Mg uptake by rice plants, which was caused by Pb toxicity. Walker *et al*. (1997) found reduced uptake of Mg as well in *Cucumis sativus* due to Pb treatment. Then again, Godbold and Kettner (1991) revealed that Pb physically blocked the entry of Mg from the absorption sites of the roots.

4.2.5.7 *Pb concentrations in straw and roots*

The mean Pb concentrations in straw and roots of Lal sak, Kalmi sak, Grass and Spinach as affected by 200 mg/kg applied Pb have been presented in Table- 4.15. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But in paired samples T- test, Pb content in straw and roots of all four test crops was found highly significant (1% level) over control (Appen.Table- 32).

Pb concentrations in the straw of four different crops under study ranged from 34.90 to 230.5 mg/kg. The highest concentration was found in the straw of Lal sak (230.5 mg/kg), followed by Spinach (161.12 mg/kg) and the lowest was found in Grass (34.90 mg/ kg). Actually, Pb

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concentration in the straw of Kalmi sak (V2) and Spinach (V4) was found statistically similar. On the other hand, the contents in the straw of Lal sak (V1) and Grass (V3) was significantly different from each other and also from Kalmi sak (V2) and Spinach (V4).

Table- 4.15: Concentrations and the transfer co-efficients of Pb in straw and roots of the test crops under study as affected by applied Pb (200 mg/kg soil)

Crop Types		Pb Concentrations			
Denotations	**Name**	**Straw**		**Roots**	
		Conc. (mg/kg)	**TC**	**Conc. (mg/kg)**	**TC**
V1	**Lal sak**	230.50 a B	1.153	327.54 a A	1.638
V2	**Kalmi sak**	144.30 b B	0.723	255.37 c A	1.277
V3	**Grass**	34.90 c B	0.175	225.60 d A	1.128
V4	**Spinach**	161.20 b B	0.806	276.01 b A	1.38
CV	**-**	6.19%	-	3.42%	

Mean values with the same letter in the same row (C letters) and the same column (S letters) are not significantly different (p=0.05)

Like straw, Pb concentrations in the roots of four crops under investigation ranged from 225.60 to 327.54 mg/ kg. The highest content was found in the roots of Lal sak (327.54 mg/ kg), followed by Spinach (276.01 mg/ kg) and the lowest was found in Grass (225.60 mg/ kg). In fact, Pb concentration in the roots of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) was found significantly different from each other. It was important to mention that Pb contents in both straw and roots of all four test crops were found highly significant over control. The transfer co-efficients of Pb in the straw and roots of different crops ranged from 0.806 to 1.153 and 1.128 to 1.638, respectively (Table- 4.15). On the other hand, Pb concentration in the straw and roots of the crops under study exhibited the following descending order: Roots > straw.

It was evident that the highest Pb concentration was found in the straw and roots of Lal sak and the lowest was found in the straw and roots of Grass. On the other hand, Pb concentration in the straw and roots of Kalmi sak and Spinach was also found high, while in the straw and roots of Grass, it was found very low. So, Lal sak, Kalmi sak and Spinch were been considered as the most Pb accumulating plants than Grass. Market (1993) reported that plant species had a variety of capacities in removing and accumulating heavy metals. He also added that specific plant species may accumulate specific heavy metal. Sharma and Kansel (1986) noticed that the vegetables, especially leafy vegetables accumulated higher amount of heavy metals.

Likewise, many researchers (Hibben *et al*., 1984; Ullah *et al*., 1999) also agreed with the statement. And they revealed that the leafy vegetables like Indian spinach had a higher tendency to take up large amount of Pb. On the other hand, Alloway (1995) reported that

heavy metal absorption was governed by soil characteristics such as pH and organic matter content. And, he also added that the high levels of heavy metals in soils did not always indicate high concentration in plants. He further added that the extent of accumulation and toxic level depend on the plant and heavy metal species. It is very important to note that dicotyledonous crops tend to absorb more metals than monocotyledonous crops (Kabata-Pendias, 1993). However, Naser *et al*. (2011) reported that different varieties of amaranth and spinach accumulated high Pb, but amaranth species accumulated more Pb than spinach from contaminated soils. They also observed that those plant species accumulated more Pb than Cd. Weaam *et al*. (2012) revealed that *Amaranthus tricolor* was capable of hyper accumulate Pb, whereas Kalmi sak (*Ipomoea aquatica*) was also recommended as Pb hyperaccumulator (Rahman *et al*., 2007).

On the other hand, Rotkittikhun *et al*. (2007) acknowledged some Pb (10-750 mg/ kg in soil) tolerant grass varieties which showed a good growth performance. Likewise, Igoshina and Kositcin (1990) also identified some Pb tolerant grass varieties and revealed that the capacity of Pb tolerance was variety dependent. In addition, Pb tolerance of grasses might be due to the secretion of oxalate from the roots and *in situ* inactivation of Pb by precipitating as Pb-oxalate. Other mechanisms such as sequestration and compartmentalization of Pb in the root vacuoles of grasses might be involved in Pb tolerance of grasses as like as rice. Broyer *et al*. (1972) and Kumar *et al*. (1995) concluded that the large portion of Pb taken up by plants remained in roots.

4.2.6 Growth, Yield, Mineral Nutrition and Cd Contents of Different Leafy Vegetable Crops and a Grass as Affected by Applied Cd (15 mg/kg soil) (Experiment- 3b)

4.2.6.1 *Fresh and dry matter yield*

The growth and physical appearance of 65 days old three different leafy vegetables and a grass crop under study as affected by 15 mg/kg Cd over control have been depicted in Plate - 18. The mean values of fresh weight and dry matter yield of the test crops under study (Lal sak, Kalmi sak, Grass and Spinach) as affected by 15 mg/kg applied Cd are presented in Table- 4.16. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found significant at 1% level. But, in paired samples T- test, the fresh weight and dry weight of Spinach and Lal sak were found significant at 5% level and 1% level, respectively over control. On the other hand, the fresh weight and dry weight of Kalmi sak and Grass were found insignificant over control (Appen.Table- 33).

Plate- 18: The growth and physical appearance of three leafy vegetables and a grass crop as affected by Cd (15 mg/kg soil) treatments over control

The fresh weight of four different test crops under investigation ranged from 5.69 to 56.10 g/ pot. The highest fresh weight was obtained in Grass (56.10 g/pot), followed by Kalmi sak (45.97 g/pot) and the lowest was obtained in Lal sak (5.69 g/pot). In fact, the fresh weight of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) varied significantly among them. On the other hand, the reduction of fresh weight of the investigated crops ranged from 3.92 to 84.14% (Figure- 4.33). Substantially high fresh weight reduction was found in Lal sak (Plate- 21) and the lowest was in Grass (3.92%) over control.

The dry weight of four different crops ranged from 0.54 to 8.77 g/ pot. The highest dry weight was obtained in Grass (8.77 g/pot), followed by Kalmi sak (4.15 g/pot) and the lowest was obtained in Lal sak (0.54 g/pot). As a matter of fact, the dry weight of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) varied significantly among them.

Then again, the reduction of dry weight of different crops under study ranged from 2.95 to 85% (Figure- 4.33). The highest reduction was recorded in Lal sak (85%) and the lowest was found in Grass (2.95%) over control. It was evident that Grass (Jumboo grass) produced the highest fresh weight, followed by Kalmi sak and the lowest was obtained in Lal sak (per pot). Conversely, the highest (84.15%) yield reduction was found in Lal sak and the lowest (3.92%) was in Grass over control.

Table- 4.16: Fresh and dry weight of the test crops under study as affected by applied Cd (15 mg/kg soil)

Crop Types		Fresh weight (g/pot)	Dry weight (g/pot)
Denotations	Crops		
V1	Lal sak	5.69 d	0.54 d
V2	Kalmi sak	45.97 b	4.15 b
V3	Grass	56.10 a	8.77 a
V4	Spinach	30.83 c	2.90 c
CV	-	3.15%	4.40%

Mean values with the same letter in the same column are not significantly different (p=0.05)
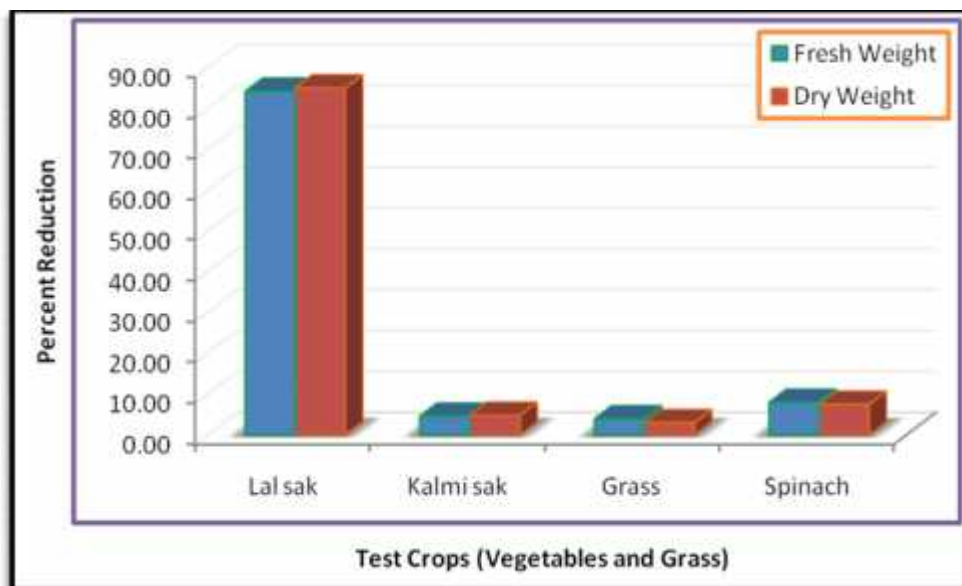
Figure- 4.33: Percent reduction of fresh weight and dry weight of four crops under study as affected by applied Cd (15 mg/kg soil) over control

The yielding abilities of four different crops varied significantly among them. On the other hand, the yields of Grass and Kalmi sak had not been significantly affected by 15 mg/kg applied Cd, whereas the growth of Lal sak had been substantially affected by 15 mg/kg applied Cd (Plate- 18). The results were in accordance with the findings of Bingham *et al*. (1975) and Tiryakiaglu *et al*. (2006). They reported that plant species and cultivars displayed distinct differences for Cd tolerance.

The results were supported by the earlier findings of Lenoczky *et al*. (1997). They found a maximum fresh weight reduction of 43% (at 100 mg/L Cd in relation to the control plant) in corn shoot. Oppositely, Morel *et al*. (1994) reported an increase in fresh yield and dry matter yield with the low Cd concentration level both by lettuce and other crops. And, a reverse phenomenon was also observed by Gracia and Lopez (1996), who found a 29% drop in yield

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of lettuce growth at 10 ppm Cd level. Likewise, Lenoczky *et al*. (1997) found that Cd reduced the dry matter yield in Lettuce and Spinach. They also observed the reduction of dry matter yield of maize due to Cd application. On the other hand, Morel *et al*. (1994) reported that root had been less affected by Cd than shoots.

Many researchers worked out that some *Amaranthus* cultivars were low Cd accumulator and some were high Cd accumulator with dramatically decreased biomass production (Web., 5). On the other hand, Sakulkoo *et al*. (2005) reported that transgenic *Ipomoea aquatica* expressing adenosine phosphosulphate reductase showed tolerance against sulfide and Cd. Similarly, Moontongchoon *et al*. (2008) stated that some transgenic plants like *Ipomoea aquatica* expressing serine acetyltransferase and cystein synthatase could mitigate detrimental effect of Cd toxicity.

4.2.6.2 *Nitrogen contents in straw and roots*

The mean N contents in straw and roots of the four test crops under investigation as affected by 15 mg/kg applied Cd are presented in Appen.Table- 34 and Figure- 4.34. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But, in paired samples T- test, N concentration in straw and roots of Spinach and Lal sak was found significant at 5% and 1% level, respectively over control. On the other hand, N content in the straw and roots of Kalmi sak and Grass was found insignificant over control (Appen.Table- 34).

Nitrogen content in the straw of four different crops under study ranged from 2.08 to 3.54%. The highest was found in the straw of Spinach (3.54%), followed by Kalmi sak (3.19%) and the lowest was found in Lal sak (2.08%).
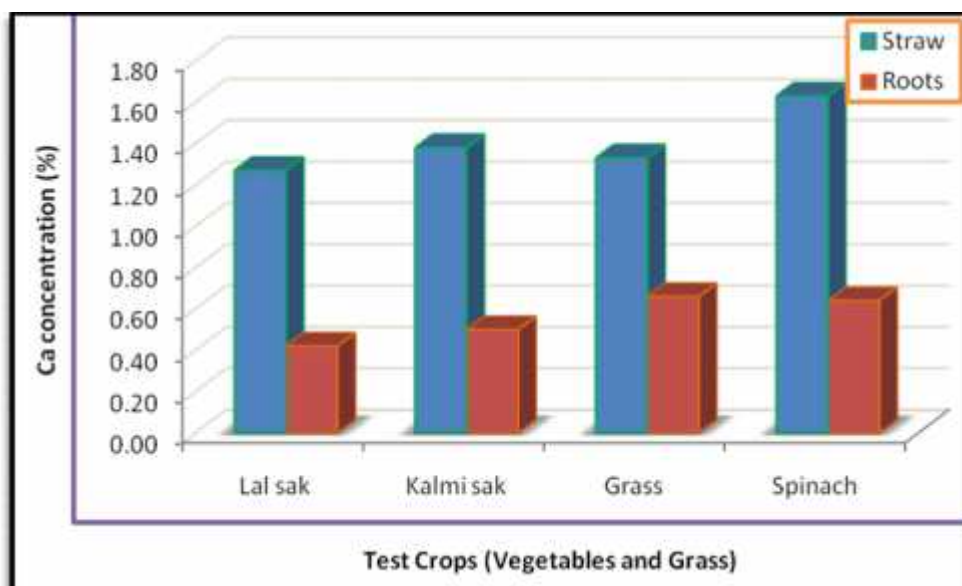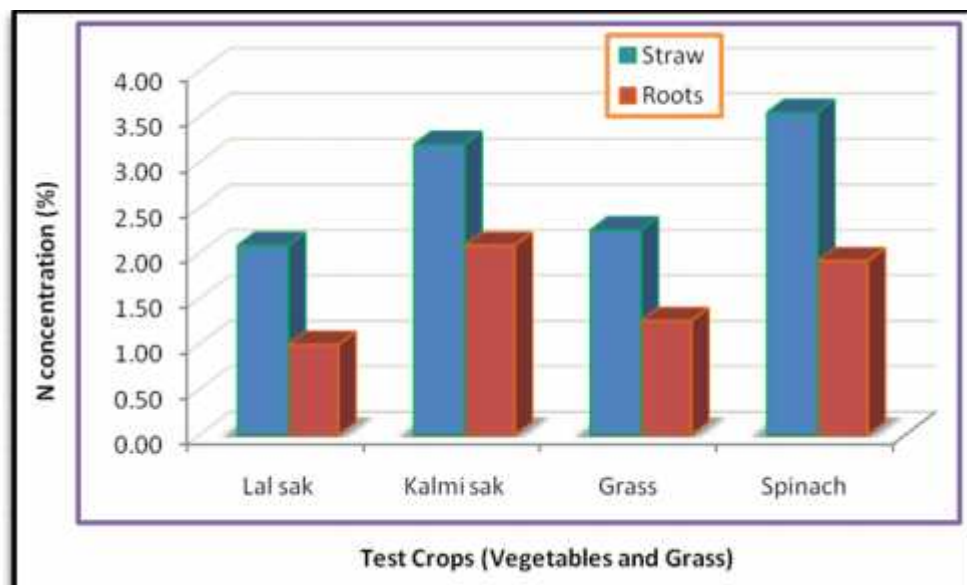

Figure- 4.34: Nitrogen concentrations in straw and roots of four different crops under study as affected by applied Cd (15 mg/kg soil)

On the other hand, N content in the roots of four different crops varied from 0.99 to 2.08%. The highest content was found in the roots of Kalmi sak (2.08%), followed by Spinach (1.91%) and the lowest was found in Lal sak (0.99%). As a matter of fact, N content in the straw and roots of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) varied significantly among them. Then again, N contents in the straw and roots of Lal sak and Spinach had been significantly affected by 15 mg/kg applied Cd, while Kalmi sak and Grass remained unaffected over control. The highest N content was found in the straw of Spinach and roots of Kalmi sak, while the lowest was found in the straw and roots of Lal sak.

Nitrogen content in the crops depends on the intensity of photosynthesis and the presence of chlorophyll, because N is an integral part of chlorophyll pigment. So, the N concentration in the straw and roots of different vegetables and grass crops might vary among them, as the rate and intensity of photosynthesis of different crops were different. On the other hand, many scientists (Karim *et al.*, 2012; Chatzistathis *et al.*, 2009; Chatzistathis *et al.*, 2012) reported that the nutrient utilization efficiency of different species of crops varied differently among them. However, a slight reduction of N contents was found in Kalmi sak and Grass, whereas in the straw and roots of Lal sak and Spinach, it was found significant over control. The results were in agreement with Bingham *et al.* (1975) and Tiryakiaglu *et al.* (2006). They reported that plant species and cultivars displayed marked differences for Cd accumulation and tolerance. Cunningham (1977) revealed that Cd restricted the transfer of N from roots to shoot. Similarly, Iwai *et al.* (1975) observed a depressive effect of Cd on N uptake in plants. Likewise, Gomes *et al.* (1985) reported that heavy metals inhibited the N uptake by plants, whereas Morel *et al.* (1994) observed the same circumstances for Cd in tomato.

4.2.6.3 *Phosphorus contents in straw and roots*

The mean values of P concentration in the straw and roots of four different test crops as affected by 15 mg/kg applied Cd are presented in Appen.Table- 34 and in Figure- 4.35. The test of significance of the P content in the straw and roots of crops was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But, in paired samples T- test, the content in the straw and roots of Lal sak was found significant at 1% and 5% level, respectively, whereas the straw and roots of Spinach was found significant at 5% level over control. On the other hand, P concentration in straw and roots of Kalmi sak and Grass was found insignificant over control (Appen.Table- 35).

Phosphorus concentration in the straw of three leafy vegetables and a grass crop under investigation varied from 0.16 to 0.43%. The highest content was found in the straw of Kalmi sak (0.43%), followed by Spinach (0.31%) and the lowest was found in the straw of Lal sak (0.16%). However, the concentration in the straw of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) was found significantly different from each other.
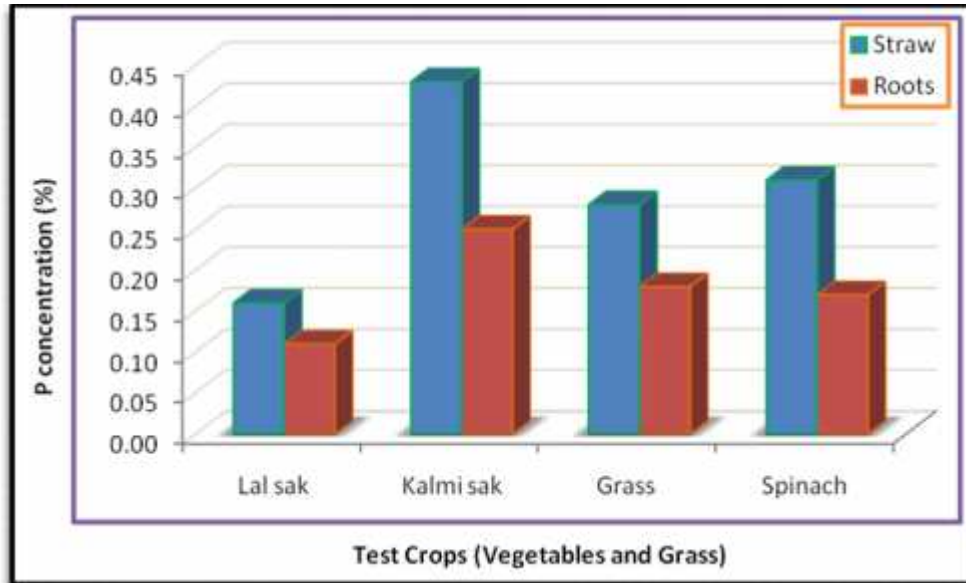
Figure- 4.35: P concentrations in straw and roots of four different crops under study as affected by applied Cd (15 mg/kg soil)

Like straw, P concentration in the roots of crops under study varied from 0.11 to 0.25%. The highest content was observed in the roots of Kalmi sak (0.25%), followed by Grass (0.18%) and the lowest was found in Lal sak (0.11%). As a matter of fact, P in roots of Grass (V3) and Spinach (V4) was found statistically similar. On the other hand, the content in Lal sak (V1) and Kalmi sak (V2) was found significantly different from each other and also from Grass (V3) and Spinach (V4).

The highest P content was found in the straw and roots of Kalmi sak and the lowest was found in the straw and roots of Lal sak. When compared with control, a significant reduction of P concentration was found in the straw and roots of Lal sak and Spinach. On the other hand, the content in the straw and roots of Kalmi sak and Grass was not significantly affected by 15 mg/kg Cd over control. The result was in agreement with the finding of Tiryakiaglu *et al*. (2006). A marked difference among varieties in Cd accumulation and tolerance was observed by Bingham *et al*. (1975) and Tiryakiaglu *et al*. (2006). Phosphorus contents in the straw and roots of test crops differed among them. The results were in accordance with Baligar *et al*. (2001) and Jiang (2006). They found a variation in nutrient accumulation competence among different species of crops. On the other hand, Krupa *et al*. (1999) observed an antagonistic effect of Cd and P in rye leaf. Similarly, Godbold and Hutterman (1985) observed that Cd induced P deficiency in plants. Likewise, Das *et al*. (1997) also revealed that the uptake, transport and use of P were interfered by Cd in plants. It was also reported that P contents decreased in soybean (Walker *et al*., 1979), in rye grass (Bonnet *et al*., 2000) and in green gram (Vijayarenjan, 2005) with an increasing trend of Ni concentration in soils.

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4.2.6.4 *Potassium contents in straw and roots*

The mean values of K concentrations in straw and roots of four different test crops under investigation as affected by 15 mg/kg applied Cd are presented in Appen.Table- 34 and Figure- 4.36. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But, in paired samples T- test, K content in the straw and roots of Lal sak was found significant at 1% and 5% level, respectively, whereas the straw and roots of Spinach was found significant at 1% level over control. On the other hand, the concentration in the straw and roots of Kalmi sak and Grass was found insignificant as compared to that of control (Appen.Table- 35).
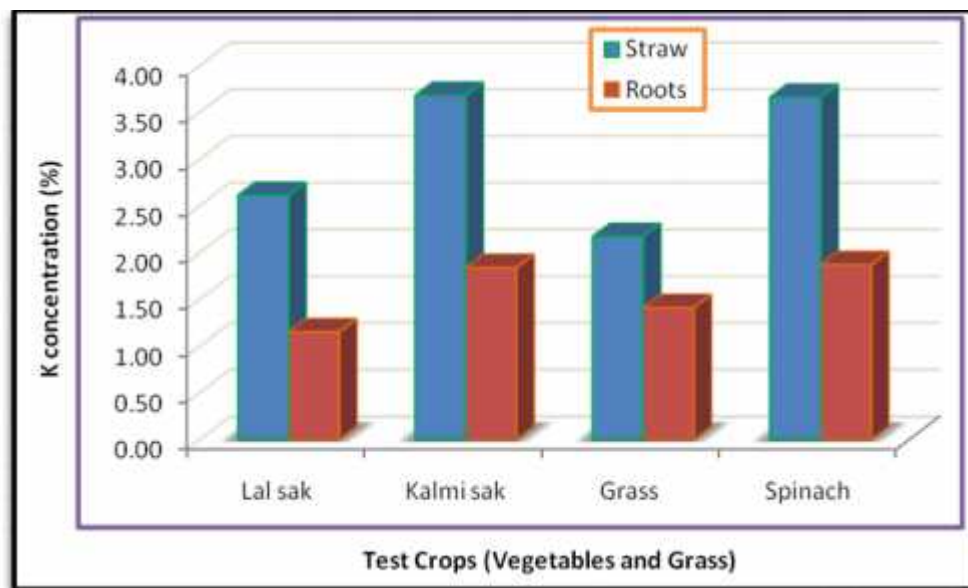
**Figure- 4.36: K concentrations in straw and roots of four different crops under study
as affected by applied Cd (15 mg/kg soil)**

Potassium content in the straw of four different test crops under study ranged from 2.17 to 3.68%. The highest concentration was found in the straw of Kalmi sak (3.68%) closely followed by Spinach (3.66%) and the lowest was found in Grass (2.17%). In fact, K content in the straw of Kalmi sak (V2) and Spinach (V4) was found statistically similar. On the other hand, K in Lal sak (V1) and Grass (V3) was found significantly different from each other and also from Kalmi sak (V2) and Spinach (V4).

Potassium content in the roots of four different crops varied from 1.15 to 1.87%. The highest concentration was found in the roots of Spinach (1.87%), followed by Kalmi sak (1.84%) and the lowest was found in Lal sak (1.15%). But, K content in the roots of Kalmi sak (V2) and Spinach (V4) was found statistically similar. On the contrary, the concentration in Lal sak (V1) and Grass (V3) was found significantly different from each other and also from Kalmi sak (V2) and Grass (V3).

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The highest K was found in the straw and roots of Kalmi sak and the lowest was found in the straw of Grass and roots of Lal sak. A variation in K content was found among the straw and roots of all the four crops. Some scientists (Chatzistathis *et al*., 2009; Karim *et al*., 2012; Chatzistathis *et al*., 2012) found a difference in nutrient use efficiency of different species of crops. On the other hand, K content in the straw and roots of Spinach and Lal sak had been severely affected by applied Cd, whereas an insignificant reduction was observed in both straw and roots of Kalmi sak and Grass over control. The results were in accordance with Bingham *et al*. (1975) and Tiryakiaglu *et al*. (2006). They observed a marked difference in Cd accumulation and tolerance of different plant species and cultivars. On the other hand, Gussarsson (1994) reported a gradual declining trend of K concentration in *Betula pendula* due to rise in Cd level in soils. Similarly, Vijayarenjan (2012) found that Cd reduced K uptake by rice.

4.2.6.5 *Calcium contents in straw and roots*

The mean values of Ca content in the straw and roots of the four test crops under investigation as affected by 15 mg/kg applied Cd are presented in Appen.Table- 34 and Figure- 4.37. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But, in paired samples T- test, Ca content in the straw and roots of Lal sak and Spinach was found significant at 1% and 5% level, respectively over control. On the other hand, Ca concentration in the straw and roots of Kalmi sak and Grass was found insignificant over control (Appen.Table- 36).

Calcium concentration in the straw of four different crops under study varied from 0.76 to 1.61%. The highest content was found in the straw of Spinach (1.61%), followed by Kalmi sak (1.46%) and the lowest was found in Lal sak (0.76%).
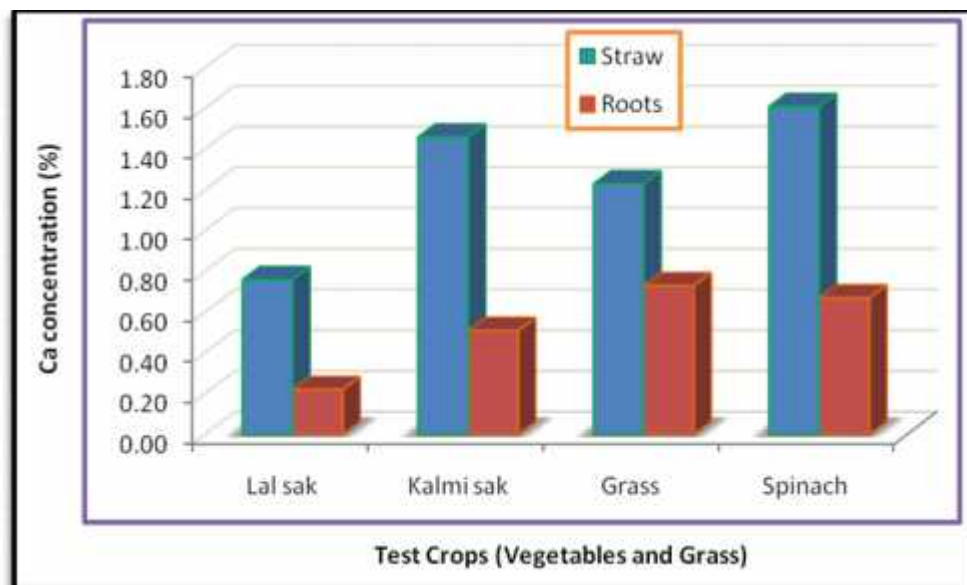
Figure- 4.37: Ca concentrations in straw and roots of four different crops under study as affected by applied Cd (15 mg/kg soil)

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Like straw, Ca contents in the roots of crops varied from 0.22 to 0.73%. The highest was found in the roots of Grass (0.73%), followed by Spinach (0.67%) and the lowest was found in Lal sak (0.22%). As a matter of fact, Ca content in the straw and roots of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) varied significantly among them.

The highest Ca content was found in the straw of Spinach and roots of Grass and the lowest was obtained in the straw and roots of Lal sak. It was observed that Ca contents in the straw and roots of Lal sak, Kalmi sak, Grass and Spinach varied significantly among them. The results were in consonance with Jiang (2006) and Yang *et al.* (2011). They reported that the nutrient uptake and utilization efficiency of different cultivar of the same plant species and/or different species of plants differed greatly among them.

On the other hand, Ca content in both straw and roots of all the four crops had been affected by applied Cd, whereas a significant reduction was observed in Spinach and Lal sak over control. It might be due to variation in the tolerance capacity or susceptibility of crops to Cd stress. Tiryakiaglu *et al.* (2006) revealed that plant species and cultivars displayed marked differences in Cd accumulation and tolerance. Then again, Cunningham (1977) and Iwai *et al.* (1975) revealed that Ca uptake in plants was affected Cd. Similarly, Vijayarengan (2012) observed an antagonistic effect of Cd with Ca in rice. It was also reported by some scientists (Bonnet *et al.*, 2000; Stoyanova and Doncheva, 2002) that Zn toxicity reduced Ca in plants.

4.2.6.6 *Magnesium contents in straw and roots*

The mean values of Mg in the straw and roots of four crops under study as affected by 15 mg/kg applied Cd are presented in Appen.Table- 34 and Figure- 4.38. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). But, in paired samples T- test, Mg content in the straw and roots of Lal sak and Spinach was found significant at 1% and 5% level, respectively over control. On the other hand, Mg content in the straw and roots of Kalmi sak and Grass was found insignificant over control (Appen.Table- 36).

Magnesium content in the straw of four test crops under investigation varied from 0.64 to 1.03%. The highest content was found in the straw of Grass (1.03%), followed by Spinach (0.91%) and the lowest was found in Lal sak (0.64%). Like straw, Mg content in the roots of crops varied from 0.12 to 0.38%. The highest was found in the roots of Grass (0.38%) and the least was obtained in Lal sak (0.12%). In fact, Ca concentration in the straw and roots of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) was found significantly different from each other.
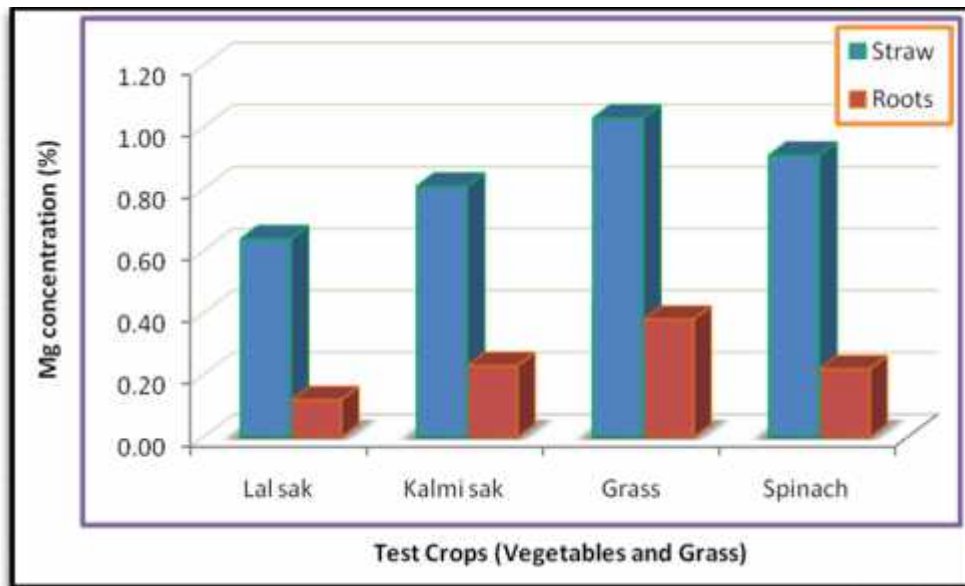
Figure- 4.38: Mg concentrations in straw and roots of four different crops under study as affected by applied Cd (15 mg/kg soil)

The highest Mg content was found in the straw and roots of Grass and the least was found in the straw and roots of Lal sak. It was obvious that Mg contents in the straw and roots of all four test crops varied significantly among them. The results were in agreement with several researchers (Chatzistathis *et al*., 2009; Chatzistathis *et al*., 2012; Karim *et al*., 2012). On the other hand, when compared with control, the reduction of Mg content was found in the straw and roots of all four crops, whereas a significant reduction was observed in the straw and roots of Lal sak and Spinach. It might be due to the effect of Cd on the growth and mineral nutrition of plants varied among different species of crops as reported by Tiryakiaglu *et al*. (2006). Similarly, Bingham *et al*. (1975) revealed that plant species exerted noticeable differences with regard to Cd uptake, accumulation and tolerance by plants. Conversely, Cunningham (1977) and Iwai *et al*. (1975) worked out that Cd restricted Mg uptake by plants. Similarly, when Krupa *et al*. (1999) studied the effect of Cd on rye, they found that Cd reduced Mg concentration in the leaves of rye. Agarwal *et al*. (1987) reported that the decreased Mg content in plant might be due to Cd treatment.

4.2.6.7 *Cd concentrations in straw and roots*

The mean values of Cd in the straw and roots of different leafy vegetables and grass under study as affected by 15 mg/kg applied Cd are presented in Table- 4.17. The test of significance was computed by Duncan's Multiple Range Test (DMRT) and it was found highly significant (1% level). And in paired sample T- test, Cd concentration in the straw and roots of all four crops was also found highly significant (1% level) over control (Appen.Table- 37).

Cadmium contents in the straw of four different crops under study ranged from 22.38 to 113.30 mg/kg. The highest content was found in the straw of Lal sak (113.33 mg/kg),

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followed by Kalmi sak (69.56 mg/kg) and the lowest was found in Grass (22.38 mg/kg). On the other hand, Cd concentration in the roots of crops ranged from 127.95 to 278.33 mg/kg. The highest content was found in the roots of Kalmi sak (278.30 mg/ kg), followed by Lal sak (198.30 mg/ kg) and the lowest was found in the roots of Grass (127.95 mg/kg). As a matter of fact, Cd concentration in both straw and roots of Lal sak (V1), Kalmi sak (V2), Grass (V3) and Spinach (V4) was found significantly different from each other. The transfer co-efficients of Cd in the straw and roots of test crop varieties ranged from 1.49 to 7.55 and 8.53 to 18.55, respectively (Table- 4.17). Cd concentration in the straw and roots of all the crops under study exhibited the following descending order: Roots > Straw.

Table- 4.17: Concentrations and the transfer co-efficients of Cd in straw and roots of the test crops under study as affected by applied Cd (15 mg/kg soil)

Crop Types		Cd Concentrations			
		Straw		Roots	
Denotations	**Crops**	Conc. (mg/kg)	TC	Conc. (mg/kg)	TC
V1	**Lal sak**	113.30 a B	7.55	198.30 b A	13.22
V2	**Kalmi sak**	69.56 b B	4.64	278.30 a A	18.55
V3	**Grass**	22.38 d B	1.49	127.95 d A	8.53
V4	**Spinach**	34.83 c B	2.32	153.70 c A	10.24
CV	-	17.69%	-	0.93%	-

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Mean values with the same letter in the same row (capital letters) and the same column (small letters) are not significantly different (p=0.05)

It was observed that the highest Cd concentration was found in the straw of Lal sak and the least was found in Grass. On the other hand, the highest content was found in the roots of Kalmi sak and the least was found in the roots of Grass. And, a significant variation in Cd concentration was found among all the four crops under study. Tiryakiaglu *et al*. (2006) reported that plant species and cultivars displayed marked differences for Cd accumulation and tolerance, which were evident from physiological processes like decline in production of reactive oxygen species and enhanced antioxidative defense systems. On the other hand, due to genetic variation among cultivars within a plant species, Cd uptake and accumulation in various plant parts also differed. The differences were also observed by John and Van Laerhoven (1970) in lettuce, Boggess *et al*. (1978) in soybean, Chino (1981) in rice, CAST (1980) in Corn and Chang *et al*. (1982) in wheat and barley. In the present study, Cd concentration in the roots of all the test crops was found several times higher than the straw. But, Cd concentration in the straw of Lal sak was found substantially higher than other crops, which might be associated with the substantial reduction of fresh weight of Lal sak (84.15%). Hong-Li and Wei (2009) identified some Cd (25 mg/kg soil) tolerant amaranthus crops after screening some cultivars. They considered amaranthus cultivar Tianxilgui as a Cd hyper-accumulator, because they accumulated 212 mg/kg Cd and could be used in phyto-remediation of Cd contaminated soils. Similarly, Zhang *et al*. (2010) reported that *amaranths hybridus* accumulated 241.56 mg/kg Cd in shoot and had the potential phyto-remediation

capability in Cd polluted soils. On the other hand, Wang *et al*. (2009) found that water Spinach accumulated high Cd and its accumulating ability was a stable biological property at cultivar level and that was also a genotype dependent property. They further reported that the compartmentalization of Cd in root and cell wall fragment might be the mechanism leading to its low Cd accumulation property. In the same way, Salasker *et al*. (2011) found that Spinach had taken up substantial amount of Cd in shoots without visual toxicity effect on Spinach up to 20 mg/kg Cd and was considered as a Cd- tolerant crop. Baker *et al*. (2000) and Chunilall *et al*. (2005) also reported that Spinach was a Cd and Hg hyper-accumulating plant. On the contrary, Bingham *et al*. (1975) revealed that plant species exerted marked differences with regard to Cd uptake, accumulation and tolerance by plants.

Sensitive crops grown in the greenhouse, such as, spinach, curly cress, romanic lettuce, soybean and field bean had their yield reduced 25% by soil Cd additions of as low as 5 to 15 ppm (Adriano, 1986). Bingham *et al*. (1976) reported that among potted soil under green house conditions, the sensitivity increased in the order: Bermuda grass < fescues < clover < alfalfa < sudangrass. According to Adriano *et al*. (1980), translocation and accumulation of Cd uptake among different plant parts vary in relation to cultivar. In general, Cd concentrations are lower in seed, tuber and fruit tissues, relative to the concentration in other parts such as roots and other leafy tissues as those in lettuce, spinach and tobacco. According to Nishizono *et al*. (1989), the bulk of Cd remained in the roots of plants. Several researchers (Penner *et al*., 1995; Athur *et al*., 2000; Zhang *et al*., 2002) revealed that the uptake of Cd could vary considerably among the species and also among cultivars within a species.

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Appen. Table- 1: Mean and SD of pH, EC, Conductivity, Turbidity and TDS of the Wastewaters Collected from Different Industrial Areas in and Around Dhaka

Industrial clusters	pH		EC (µS/cm)		Conductivity (µS/cm)		Turbidity (NTU)		TDS(mg/L)	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Ashulia	7.70	0.61	745.50	459.15	874.75	469.04	76.25	110.57	615.25	374.53
Demra	6.47	3.09	998.00	427.07	1092.30	416.52	65.33	55.64	765.33	289.52
Gazipur	8.57	1.69	827.75	242.31	959.25	259.26	85.88	43.31	671.12	194.00
Hazaribagh	7.75	0.49	5000.00	707.11	5656.50	65.76	373.50	342.95	3964.00	49.50
Hotapara	7.28	0.20	834.33	102.69	954.33	128.90	247.67	131.70	666.67	90.74
Keranigonj	6.18	1.82	1714.50	2705.99	1814.00	2731.72	33.00	26.01	1279.50	1904.16
Matuail	9.05	1.06	1060.30	1088.28	1237.00	1125.81	18.33	10.21	858.33	774.65
Savar	7.80	1.27	902.00	551.54	1044.00	519.00	24.00	8.49	741.00	352.14
Shampur	8.40	0.36	967.33	173.49	1076.30	158.57	19.33	12.70	758.33	113.20
Tejgaon	8.18	0.06	743.00	60.80	840.00	59.10	5.56	0.58	601.00	35.68

Appen. Table- 2: Mean and SD of DO, NO_2^--N, NO_3^--N, NH_4^+-N and SO_4^{2-} of the Wastewaters Collected from Different Industrial Areas in And Around Dhaka

Industrial clusters	DO (mg/L)		NO_2^--N (µg/L)		NO_3^--N (mg/L)		NH_4^+-N (mg/L)		SO_4^{2-} (mg/L)	
	Mean	± SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	± SD
Ashulia	1.55	0.82	260.00	230.22	8.48	5.49	12.87	15.25	93.25	96.72
Demra	1.03	0.58	171.00	71.71	107.34	173.79	17.33	23.97	50.00	71.27
Gazipur	1.01	0.48	303.00	180.64	8.25	3.24	7.25	3.92	126.25	158.40
Hazaribagh	0.10	0.14	1905.00	63.64	137.50	10.60	217.50	17.68	728.50	72.83
Hotapara	0.87	0.15	170.00	26.46	15.67	8.62	13.00	3.00	380.33	36.61
Keranigonj	2.85	1.85	86.25	62.63	7.88	4.90	1.75	1.70	1954.20	3763.59
Matuail	1.87	0.25	604.33	827.65	11.00	11.27	6.50	2.78	124.67	83.09
Savar	1.70	0.28	135.50	20.50	20.50	3.53	17.50	6.36	500.00	565.69
Shampur	2.03	0.29	196.67	55.07	11.00	9.16	4.33	2.08	200.33	148.32
Tejgaon	3.33	0.06	35.33	21.57	4.33	2.08	3.67	1.53	38.67	6.43

Appen.Table- 3: Mean and SD of HCO_3^-, CO_3^{2-}, T. Alkalinity, PO_4^{3-} and Cl^- of the Wastewaters Collected from Different Industrial Areas in and Around Dhaka

Industrial clusters	HCO_3^- (mg/L)		CO_3^{2-} (mg/L)		T. Alkalinity (mg/L)		PO_4^{3-} (mg/L)		Cl^- (mg/L)	
	Mean	±SD	Mean	±SD	Mean	± SD	Mean	±SD	Mean	±SD
Ashulia	280.00	142.01	62.50	125.00	293.75	209.31	12.25	6.65	337.50	184.43
Demra	376.33	435.92	113.33	196.30	497.87	676.50	22.67	5.03	143.33	100.75
Gazipur	367.00	197.21	135.00	252.76	526.38	309.16	31.50	16.38	182.62	46.89
Hazaribagh	465.00	35.35	0.00	0.00	381.30	28.99	69.50	7.78	4505.00	1408.55
Hotapara	456.67	30.53	0.00	0.00	374.47	25.00	20.67	2.08	500.67	33.31
Keranigonj	118.75	110.02	0.00	0.00	97.37	90.22	11.76	17.63	103.25	71.56
Matuail	203.33	103.41	266.67	236.29	612.07	318.23	40.67	47.02	422.67	258.77
Savar	538.50	253.85	85.00	120.21	560.00	290.76	17.00	1.41	208.50	27.57
Shampur	480.00	40.00	50.0	20.0	477.10	66.20	24.33	23.11	374.67	23.35
Tejgaon	314.67	21.22	20.0	20.0	280.27	280.24	15.67	2.08	184.00	106.41

Appen. Table- 4: Mean and SD of Some Cationic Composition of Wastewaters Collected from Different Industrial Areas in and Around Dhaka

Industrial clusters	Na (mg/L)		K (mg/L)		Ca (mg/L)		Mg (mg/L)	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
Ashulia	66.75	36.20	10.50	4.43	92.50	35.71	108.88	135.98
Demra	21.00	8.54	12.00	5.29	76.02	45.03	17.03	7.17
Gazipur	93.25	60.57	25.50	26.29	70.25	27.13	33.25	10.81
Hazaribagh	1407.50	74.25	77.00	4.24	125.00	21.21	67.50	10.60
Hotapara	33.33	10.50	28.00	6.56	5.57	0.42	4.63	1.21
Keranigonj	34.25	6.18	12.00	4.97	54.00	34.31	14.02	7.30
Matuail	93.30	42.46	16.93	3.90	27.24	18.22	11.50	7.73
Savar	74.00	41.01	16.00	2.83	88.50	12.02	25.55	27.51
Shampur	36.70	24.02	24.50	3.97	20.71	11.70	10.77	6.79
Tejgaon	49.30	11.83	12.73	4.20	5.99	0.87	8.03	0.15

Appen. Table- 5: Mean and SD of Some Heavy Metal Concentrations in the Wastewaters Collected from Different Industrial Areas in and Around Dhaka

Industrial Clusters	Zn (mg/L)		Cu (mg/L)		Ni (mg/L)		Pb (mg/L)		Cd (mg/L)	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
Ashulia	0.07	0.03	0.025	0.021	0.017	0.015	0.016	0.002	0.009	0.008
Demra	6.46	11.08	0.03	0.023	0.016	0.004	0.010	0.007	0.004	0.002
Gazipur	0.92	0.26	0.03	0.033	0.084	0.134	0.023	0.03	0.007	0.004
Hazaribagh	0.50	0.07	0.032	0.02	0.007	0.001	0.028	0.005	0.0185	0.007
Hotapara	0.03	0.02	0.011	0.002	0.018	0.006	0.007	0.002	0.012	0.003
Keranigonj	3.67	7.22	1.43	2.84	0.481	0.95	1.62	2.45	0.003	0.001
Matuail	0.09	0.13	0.19	0.32	0.006	0.002	0.045	0.039	0.005	0.004
Savar	0.07	0.01	0.013	0.007	0.009	0.008	0.003	0.0007	0.006	0.001
Shampur	6.18	10.67	0.083	0.24	0.007	0.002	0.023	0.008	0.005	0.004
Tejgaon	0.06	0.03	0.023	0.032	0.037	0.022	0.013	0.002	0.007	0.002

Appen. Table- 6: Mean and SD of pH, EC, OC, Total N, Total P of the Soil Samples Collected from Different Industrial Areas in and Around Dhaka

Industrial Clusters	pH		EC (µS/cm)		OC (%)		Total N (%)		Total P (%)	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
Ashulia	6.83	0.11	283.67	164.66	2.06	0.23	0.27	0.04	0.20	0.03
Demra	6.34	1.81	396.25	204.87	1.37	0.47	0.20	0.06	0.14	0.05
Gazipur	7.47	0.75	1365.30	1005.85	1.52	0.79	0.20	0.10	0.15	0.08
Hazaribagh	6.83	0.76	3592.20	179.69	3.58	0.54	0.46	0.07	0.36	0.05
Hotapara	5.28	1.00	597.67	133.24	2.10	0.20	0.26	0.02	0.21	0.03
Keranigonj	5.83	1.99	1824.00	3053.65	1.07	0.23	0.13	0.04	0.10	0.02
Matuail	9.20	1.17	1232.30	595.82	1.50	0.60	0.19	0.08	0.16	0.05
Savar	7.52	0.46	532.00	336.44	1.87	1.30	0.24	0.16	0.19	0.12
Shampur	8.60	0.82	2255.30	1960.33	1.12	0.54	0.15	0.07	0.12	0.05
Tejgaon	8.06	0.15	1320.30	75.04	3.62	0.50	0.47	0.06	0.35	0.05

Appen.Table- 7: Mean and SD of Na, K, Ca and Mg Concentrations in Soil Samples Collected from Different Industrial Areas in and Around Dhaka

Industrial Clusters	Na (%)		K (%)		Ca (%)		Mg (%)	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
Ashulia	0.43	0.19	0.17	0.03	1.44	0.21	0.40	0.31
Demra	0.51	0.18	0.34	0.38	1.60	0.13	0.55	0.45
Gazipur	0.90	0.56	0.58	0.26	2.02	1.30	0.49	0.24
Hazaribagh	1.88	0.17	0.83	0.14	1.55	0.33	0.78	0.09
Hotapara	0.27	0.17	0.51	0.04	0.65	0.34	0.41	0.19
Keranigonj	0.53	0.35	0.15	0.04	0.82	0.95	0.33	0.31
Matuail	0.78	0.37	0.21	0.04	1.26	2.01	0.20	0.16
Savar	0.39	0.09	0.13	0.06	2.57	1.48	1.08	0.53
Shampur	1.02	0.20	0.17	0.02	2.54	2.07	0.58	0.53
Tejgaon	0.45	0.04	0.23	0.005	0.67	0.53	0.55	0.30

Appen.Table- 8: Mean and SD of Some Heavy Metal Concentrations in Soil Samples Collected from Different Industrial Areas in and Around Dhaka

Industrial Clusters	Zn(mg/kg soil)		Cu (mg/kg soil)		Ni (mg/kg soil)		Pb (mg/kg soil)		Cd (mg/kg soil)	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
Ashulia	201.67	129.45	149.67	44.56	32.67	6.66	35.00	17.69	2.50	0.62
Demra	648.00	1000.52	427.75	254.17	49.00	60.73	66.75	81.95	1.55	0.77
Gazipur	264.71	255.98	315.86	130.89	77.00	65.99	60.85	52.37	1.99	1.08
Hazaribagh	177.25	213.49	279.25	80.49	52.75	28.71	43.75	25.01	3.05	1.33
Hotapara	130.00	26.66	74.33	11.37	59.00	35.67	31.33	5.03	5.33	1.53
Keranigonj	245.50	175.54	338.85	249.30	47.62	14.99	819.00	1454.06	1.13	0.98
Matuail	824.33	150.19	241.00	201.76	31.33	14.64	60.33	39.92	2.32	1.33
Savar	255.00	140.03	121.67	67.81	81.00	23.07	22.67	3.05	2.47	0.72
Shampur	301.00	64.50	374.33	119.79	81.67	57.71	316.67	151.77	3.58	2.15
Tejgaon	280.00	44.50	113.67	46.23	39.00	1.00	23.67	10.78	1.99	0.18

Appen.Table- 9: Mean and SD of Nutrient Contents and Some Heavy Metal Concentrations in Vegetables and other Crops Collected from Different Industrial Areas in and Around Dhaka

Parameters	Kalmi sak	±SD	Spinach	±SD	Lal sak	±SD	Rice	±SD	Grass	±SD
N (%)	2.37	0.66	2.65	0.28	2.66	0.23	2.12	0.21	2.20	0.45
P (%)	0.30	0.10	0.28	0.11	0.27	0.12	0.27	0.07	0.24	0.07
Na (%)	0.71	0.29	0.54	0.21	0.66	0.28	0.61	0.26	0.73	0.24
K (%)	1.57	0.62	1.87	0.34	1.56	0.66	1.25	0.42	1.36	0.26
Ca (%)	0.90	0.46	0.97	0.64	1.66	1.06	0.60	0.49	1.66	1.58
Mg (%)	0.33	0.13	0.32	0.10	0.61	0.31	0.26	0.03	0.47	0.27
Zn (mg/kg)	286.25	200.47	235.26	133.30	498.72	593.12	67.00	29.10	142.83	85.10
Cu (mg/kg)	30.54	16.26	21.78	10.88	41.07	16.03	32.00	15.13	67.10	60.00
Ni (mg/kg)	10.31	3.76	7.90	2.58	13.68	11.17	9.33	4.64	10.37	9.37
Pb (mg/kg)	9.70	15.14	4.10	2.82	5.70	3.50	2.09	0.54	3.87	3.72
Cd (mg/kg)	2.56	1.12	2.54	1.92	1.85	0.93	1.40	0.37	1.47	0.96

Appen.Table- 10: N, P and K Concentrations in Grains, Straw and Roots of Brridhan- 28 Rice Variety as Affected by Pb- Toxicity

Treatment denotations	Applied Pb (mg/kg)	N (%)			P (%)			K (%)		
		Grains	**Straw**	**Roots**	**Grains**	**Straw**	**Roots**	**Grains**	**Straw**	**Roots**
T0	**Control**	1.87 a	1.55 a	0.95 a	0.50 a	0.41 a	0.23 a	2.53 a	1.70 a	0.37 a
T1	**100**	1.86 a	1.53 ab	0.94 ab	0.48 b	0.40 ab	0.22 ab	2.50 ab	1.69 ab	0.35 b
T2	**125**	1.84 b	1.52 b	0.93 bc	0.45 c	0.39 bc	0.21 b	2.48 bc	1.67 b	0.34 b
T3	**150**	1.83 bc	1.52 bc	0.91 d	0.43 d	0.38 c	0.19 c	2.46 cd	1.66 bc	0.32 c
T4	**175**	1.81 c	1.50 c	0.90 e	0.40 e	0.37 d	0.18 c	2.45 d	1.63 c	0.30 c
T5	**200**	1.59 d	1.37d	0.80 f	0.36 f	0.29 e	0.15 d	2.32 e	1.54 d	0.24 d
T6	**250**	1.47 e	1.30 e	0.74 g	0.32 g	0.24 f	0.12 e	2.22 f	1.50 e	0.20 e
T7	**300**	1.40 f	1.25 f	0.65 h	0.25 h	0.21 g	0.10 f	2.15 g	1.42 f	0.18 f
T8	**350**	1.30 g	1.17 g	0.56 i	0.23 i	0.20 h	0.08 g	2.00 h	1.31 g	0.16 g

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appen. Table- 11: Ca and Mg Concentrations in Grains, Straw and Roots of Brridhan-28 Rice variety as Affected by Pb- Toxicity

Treatment denotations	Applied Pb (mg/kg)	Ca (%)			Mg (%)		
		Grains	**Straw**	**Roots**	**Grains**	**Straw**	**Roots**
T0	**Control**	0.52 a	0.85 a	0.28 a	0.76 a	0.70 a	0.24 a
T1	**100**	0.49 b	0.84 ab	0.27 b	0.65 ab	0.70 ab	0.22 b
T2	**125**	0.47 c	0.83 bc	0.26 c	0.63 c	0.68 bc	0.21 b
T3	**150**	0.45 c	0.81 d	0.24 d	0.57 c	0.67 d	0.19 c
T4	**175**	0.43 d	0.79 e	0.23 e	0.55 d	0.66 e	0.18 c
T5	**200**	0.35 e	0.72 f	0.19 f	0.50 e	0.53 f	0.16 d
T6	**250**	0.31 f	0.65 g	0.17 g	0.46 f	0.47 g	0.13 e
T7	**300**	0.25 g	0.59 h	0.15 h	0.41 g	0.40 h	0.11 f
T8	**350**	0.22 h	0.50 i	0.13 i	0.37 h	0.36 i	0.09 g

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appen.Table- 12: N, P and K Concentrations in Grains, Straw and Roots of Brridhan- 28 Rice Variety as Affected by Cd- Toxicity

Treatment denotations	Applied Cd (mg/kg)	N (%)			P (%)			K (%)		
		Grains	Straw	Roots	Grains	Straw	Roots	Grains	Straw	Roots
T0	Control	1.88a	1.55 a	0.95 a	0.49 a	0.41 a	0.23 a	2.53 a	1.71 a	0.37 a
T1	3	1.74b	1.46 b	0.91 b	0.32 b	0.34 b	0.18 b	2.37 b	1.54 b	0.32 b
T2	5	1.64c	1.39 c	0.87 c	0.30 c	0.31 c	0.17 c	2.19 c	1.48 c	0.31 c
T3	7	1.54d	1.36 d	0.83 d	0.27 d	0.27 d	0.14 d	2.10 d	1.42 d	0.28 d
T4	9	1.42e	1.29 e	0.74 e	0.23 e	0.23 e	0.12 e	1.98 e	1.36 e	0.23 e
T5	15	1.26f	1.17 f	0.58 f	0.20 f	0.20 f	0.09 f	1.79 f	1.28 f	0.18 f
T6	30	1.12g	1.09 g	0.49 g	0.17 g	0.17 g	0.07 g	1.54 g	1.10 g	0.15 g
T7	60	-	-	-	-	-	-	-	-	-
T8	90	-	-	-	-	-	-	-	-	-

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appen.Table- 13: Ca and Mg Concentrations in Grains, Straw and Roots of Brridhan - 28 Rice Variety as Affected by Cd- Toxicity

Treatment denotations	Applied Cd (mg/kg)	Ca (%)			Mg (%)		
		Grains	Straw	Roots	Grains	Straw	Roots
T0	Control	0.52 a	0.85 a	0.28 a	0.67 a	0.70 a	0.24 a
T1	3	0.44 b	0.77 b	0.19 b	0.62 b	0.66 b	0.19 b
T2	5	0.38 c	0.72 c	0.17 c	0.57 c	0.64 c	0.16 c
T3	7	0.35 d	0.67 d	0.15 d	0.54 d	0.58 d	0.13 d
T4	9	0.31 e	0.65 e	0.14 e	0.49 e	0.55 e	0.11 e
T5	15	0.26 f	0.56 f	0.10 f	0.39 f	0.48 f	0.09 f
T6	30	0.20 g	0.51 g	0.09 g	0.31 g	0.42 g	0.07 g
T7	60	-	-	-	-	-	-
T8	90	-	-	-	-	-	-

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appendix- 7

Appen. Table- 14: Fresh weight, Dry weight, Grain yield (g/pot) and Percent Reduction of Five Different Varieties of Rice as Affected by Applied Pb (200 mg/kg soil) Over Control

Varieties of Rice			Raw weight			Dry weight			Grain weight		
Denotations	Name	Treatment combinations	RW (g/pot)	t- Value	Reduction (%)	DW (g/pot)	t- Value	Reduction (%)	GW (g/pot)	t- Value	Reduction (%)
V1	BR-16	V1T0	152.00	0.229 ns	0.66	31.66	3.87 ns	2.68	68.30	2.39 ns	3.22
		V1T1	151.00			30.81			66.10		
V2	BR-15	V2T0	159.0	34.77 **	19.50	34.50	42.84 **	18.29	66.36	12.67 **	29.20
		V2T1	128.00			28.19			46.98		
V3	BR-19	V3T0	187.00	4.00 ns	1.07	41.50	2.99 ns	3.61	78.40	1.99 ns	1.95
		V3T1	185.67			40.00			76.87		
V4	Brridhan-45	V4T0	185.00	1.92 ns	2.16	39.50	2.00 ns	2.53	72.20	2.43 ns	0.97
		V4T1	181.00			38.50			71.50		
V5	Brridhan-29	V5T0	173.00	2.08 ns	2.12	36.56	2.43 ns	5.83	72.00	3.23 ns	2.60
		V5T1	169.33			34.43			70.13		
CV	-	-	1.45%	-	-	2.62%	-	-	1.79%	-	-

* denotes significant at 5% level, ** denotes significant at 1% level, ns denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table- 15: N, P and K Concentrations in Grains, Straw and Roots of Five Different Varieties of Rice as Affected by Applied Pb (200 mg/kg soil)

Varieties of Rice		N (%)			P (%)			K (%)		
Denotations	Name	Grains	Straw	Roots	Grains	Straw	Roots	Grains	Straw	Roots
V1	BR-16	1.49 cd	1.21d	0.69 e	0.31 c	0.31 c	0.27 c	0.78 c	1.81 c	0.47 b
V2	BR-15	1.42 d	1.20 e	0.72 d	0.27 d	0.30 d	0.16 e	0.72 e	1.73 e	0.35 d
V3	BR-19	1.79 a	1.36 a	0.84 a	0.37 b	0.41 b	0.30 a	0.96 a	1.94 a	0.47 b
V4	Brridhan-45	1.56 bc	1.27 c	0.82 b	0.30 c	0.42 a	0.29 b	0.76 d	1.76 d	0.37 c
V5	Brridhan-29	1.63 b	1.30 b	0.75 c	0.40 a	0.32 c	0.24 d	0.80 b	1.83 b	0.49 a
CV	-	2.05%	1.13%	1.97%	4.78%	4.70%	3.75%	2.39%	0.90%	3.11%

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appen.Table- 16: Ca and Mg Concentrations in Grains, Straw and Roots of Five Different Varieties of Rice as Affected by Applied Pb (200 mg/kg soil)

Varieties of Rice		Ca (%)			Mg (%)		
Denotations	Name	Grains	Straw	Roots	Grains	Straw	Roots
V1	BR-16	0.83 b	0.90 c	0.42 b	0.71 a	0.59 d	0.30 c
V2	BR-15	0.79 c	0.69 e	0.33 e	0.57 b	0.53 e	0.19 e
V3	BR-19	0.89 a	0.95 ab	0.43 a	0.57 b	0.66 c	0.33 a
V4	Brridhan-45	0.67 d	0.86 d	0.38 c	0.45 c	0.71 b	0.32 b
V5	Brridhan-29	0.67 d	0.96 a	0.37 d	0.57 b	0.73 a	0.27 d
CV	-	2.18%	3.01%	2.93%	2.67%	2.59%	2.55%

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appen.Table- 17: N and P Contents in the Grains, Straw and Roots of Five Different Varieties of Rice as Affected by Applied Pb (200 mg/kg soil) Over Control

Varieties of Rice			Nitrogen						Phosphorus					
Denotations	Name	Treatment combinations	Grains		Straw		Roots		Grains		Straw		Roots	
			N (%)	t- Value	N (%)	t- Value	N (%)	t- Value	P (%)	t- Value	P (%)	t- Value	P (%)	t- Value
V1	BR-16	V1T0	1.55	1.732 ns	1.32	1.732 ns	0.81	3.464 ns	0.35	3.606 ns	0.32	3.464 ns	0.28	1.000 ns
		V1T1	1.54		1.30		0.79		0.31		0.30		0.27	
V2	BR-15	V2T0	1.52	11.717 **	1.27	5.196 *	0.77	5.000 *	0.34	6.102 **	0.39	11.500 **	0.27	5.261 *
		V2T1	1.41		1.21		0.72		0.27		0.31		0.16	
V3	BR-19	V3T0	1.82	3.780 ns	1.38	1.151 ns	0.86	3.464 ns	0.38	1.000 ns	0.43	2.646 ns	0.32	1.147 ns
		V3T1	1.79		1.36		0.84		0.37		0.41		0.30	
V4	Brridhan-29	V4T0	1.60	2.619 ns	1.28	1.732 ns	0.84	1.732 ns	0.32	2.500 ns	0.45	3.024 ns	0.30	1.387 ns
		V4T1	1.56		1.27		0.82		0.30		0.42		0.29	
V5	Brridhan-29	V5T0	1.67	1.589 ns	1.33	3.780 ns	0.78	4.000 ns	0.42	1.147 ns	0.34	1.606 ns	0.26	1.387 ns
		V5T1	1.63		1.30		0.75		0.40		0.32		0.24	
CV	-	-	1.76%	-	1.26%	-	1.87%	-	4.34%	-	4.70%	--	5.91%	-

* denotes significant at 5% level, ** denotes significant at 1% level and ns - denotes not significant, T0 denotes control and T1 denotes treatment

Appendix- 9

Appen.Table- 18: K and Ca Contents in the Grains, Straw and Roots of Five Different Varieties of Rice as Affected by Applied Pb (200 mg/kg soil) Over Control

Varieties of Rice			Potassium						Calcium					
			Grains		Straw		Roots		Grains		Straw		Roots	
Denotations	Name	Treatment combinations	K (%)	t- Value	K (%)	t- Value	K (%)	t- Value	Ca (%)	t-Value	Ca (%)	t-Value	Ca (%)	t-Value
V1	BR-16	V1T0	0.79	1.732 ns	1.84	2.598 ns	0.48	1.732 ns	0.85	1.732 ns	0.91	2.000 ns	0.43	0.500 ns
		V1T1	0.78		1.81		0.47		0.83		0.90		0.42	
V2	BR-15	V2T0	0.87	10.553 **	1.87	7.234 *	0.44	9.827 **	0.88	7.794 **	0.77	5.750 *	0.42	12.500 **
		V2T1	0.72		1.72		0.35		0.79		0.69		0.33	
V3	BR-29	V3T0	0.99	4.000 ns	1.97	2.219 ns	0.49	2.646 ns	0.91	3.464 ns	0.97	2.000 ns	0.45	2.000 ns
		V3T1	0.96		1.94		0.47		0.89		0.95		0.43	
V4	Brridhan-45	V4T0	0.78	1.147 ns	1.81	3.500 ns	0.39	0.945 ns	0.68	1.147 ns	0.89	3.000 ns	0.40	2.500 ns
		V4T1	0.76		1.76		0.37		0.67		0.86		0.38	
V5	Brridhan-29	V5T0	0.82	3.464 ns	1.85	3.500 ns	0.51	1.890 ns	0.70	1.732 ns	1.01	1.387 ns	0.38	1.890 ns
		V5T1	0.80		1.83		0.49		0.67		0.96		0.37	
CV	-	-	2.02%	-	0.94%	-	3.24%	-	1.62%	-	2.47%	-	3.28%	-

* denotes significant at 5% level, ** denotes significant at 1% level and ns - denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table- 19: Mg Contents in the Grains, Straw and Roots of Five Different Varieties Rice as Affected by Applied Pb (200 mg/kg soil) Over Control

Varieties of Rice			Magnesium					
			Grains		Straw		Roots	
Denotations	Name	Treatment combinations	Mg (%)	t- Value	Mg (%)	t- Value	Mg (%)	t- Value
V1	BR-16	V1T0	0.73	1.000 ns	0.61	3.464 ns	0.31	0.655 ns
		V1T1	0.71		0.59		0.30	
V2	BR-15	V2T0	0.67	4.422 **	0.65	7.000 *	0.33	12.124 **
		V2T1	0.57e		0.55		0.19	
V3	BR-19	V3T0	0.58	0.718 ns	0.69	2.219 ns	0.34	0.655 ns
		V3T1	0.57		0.66		0.33	
V4	Brridhan-45	V4T0	0.48	3.024 ns	0.73	1.941 ns	0.33	0.918 ns
		V4T1	0.45		0.71		0.32	
V5	Brridhan-29	V5T0	0.60	3.024 ns	0.76	2.774 ns	0.28	0.655 ns
		V5T1	0.57		0.73		0.27	
CV	-	-	3.11%	-	2.51%	-	5.35%	-

* denotes significant at 5% level. ** denotes significant at 1% level and ns denotes not significant. T0 denotes control and T1 denotes treatment

Appen. Table- 20: Pb Concentrations in Grains, Straw and Roots of Five Different Varieties of Rice as Affected by Applied Pb (200 mg/kg soil) Over Control

Varieties of Rice			Pb Conc. in Grains		Pb Conc. in Straw		Pb Conc. in Roots	
Denotations	Name	Treatment combinations	Pb (mg/kg)	t-Value	Pb (mg/kg)	t- Value	Pb (mg/kg)	t- Value
V1	BR-16	V1T0	0.00	-9.526 **	0.11	-16.422 **	2.63	-44.565 **
		V1T1	0.011		9.50		260.00	
V2	BR-15	V2T0	0.00	-50.00 **	0.15	-2252.00 **	2.70	-27.599 **
		V2T1	1.90		25.17		215.00	
V3	BR-19	V3T0	0.00	-8.66 **	0.36	-340.747 **	2.93	-11.960 **
		V3T1	0.005		10.77		176.70	
V4	Brridhan- 45	V4T0	0.00	-22.00 **	0.22	-338.767 **	3.53	-29.257 **
		V4T1	0.007		13.53		170.00	
V5	Brridhan- 29	V5T0	0.00	-15.588 **	0.26	-461.560 **	2.97	-18.906 **
		V5T1	0.009		14.93		166.67	
CV	-	-	10%	-	4.80%	-	9.14%	-

**denotes significant at 1% level, T0 denotes control and T1 denotes treatment

Appen. Table- 21: Fresh Weight, Dry Weight and Grain Yield (g/pot) and Percent Yield Reduction of Five Different Varieties of Rice as Affected byApplied Cd (7 mg/kg soil) Over Control

Varieties of Rice			Fresh Weight			Dry Weight			Grain Weight		
Denotations	Name	Treatment combinations	FW (g/pot)	t- Value	Reduction (%)	DW (g/pot)	t- Value	Reduction (%)	GW (g/pot)	t- Value	Reduction (%)
V1	BR-16	V1T0	155.00	25.115 **	9.67	32.913	5.051 *	9.63	66.38	5.020 *	27.26
		V1T1	140.50			29.74			48.28		
V2	BR-15	V2T0	168.00	3.031 ns	4.17	35.97	1.386 ns	2.64	64.3	1.830 ns	2.87
		V2T1	161.00			35.02			62.45		
V3	BR-19	V3T0	184.00	2.200 ns	4.34	40.13	3.700 ns	3.97	74.93	1.652 ns	1.46
		V3T1	176.67			38.90			73.83		
V4	Brridhan- 45	V4T0	177.00	3.213 ns	3.34	38.46	2.897 ns	3.29	71.10	2.603 ns	2.62
		V4T1	171.33			37.20			69.23		
V5	Brridhan- 29	V5T0	188.00	0.548 ns	1.59	41.02	1.185 ns	2.14	77.82	2.138 ns	0.98
		V5T1	185.67			40.14			77.07		
CV	-	-	1.81%	-	-	1.66%	-	-	2.60%	-	-

* denotes significant at 5% level, ** denotes significant at 1% level and ns denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table- 22: N, P and K Contents in Grains, Straw and Roots of Five Different Rice Varieties as Affected by Applied Cd (7 mg/kg soil)

Varieties of Rice		N (%)			P (%)			K (%)		
Denotations	Name	Grains	Straw	Roots	Grains	Straw	Roots	Grains	Straw	Roots
V1	BR-16	1.40 d	1.11 d	0.60 e	0.28 d	0.22 d	0.20 d	0.72 e	1.64 c	0.47 ab
V2	BR-15	1.54 c	1.25 c	0.75 d	0.32 bc	0.25 c	0.22 c	0.82 b	1.69 bc	0.45 ab
V3	BR-19	1.80 a	1.34 a	0.84 a	0.37 a	0.29 a	0.25 a	0.97 a	1.79 ab	0.48 ab
V4	Brridhan-45	1.51 c	1.24 c	0.80 b	0.32 c	0.27 b	0.24 b	0.77 d	1.74 abc	0.41 b
V5	Brridhan-29	1.63 b	1.28 b	0.77 c	0.33 b	0.25 c	0.24 b	0.79 c	1.84 a	0.52 a
CV	-	1.46%	1.79%	1.66%	5.54%	4.97%	5.46%	1.43%	2.38%	5.04%

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appen.Table- 23: Ca and Mg Contents in Grains, Straw and Roots of Five Different Rice Varieties as Affected by Applied Cd (7 mg/kg soil)

Varieties of Rice		Ca (%)			Mg (%)		
Denotations	Name	Grains	Straw	Roots	Grains	Straw	Roots
V1	BR-16	0.74 bc	0.85 d	0.32 e	0.51 d	0.50 e	0.20 d
V2	BR-15	0.86 a	0.98 c	0.48 a	0.66 a	0.65 d	0.32 b
V3	BR-19	0.79 ab	0.96 c	0.43 c	0.60 b	0.67 c	0.30 c
V4	Brridhan-45	0.66 c	1.25 b	0.38 d	0.47 e	0.71 b	0.32 b
V5	Brridhan-29	0.74 bc	1.37 a	0.47 b	0.58 c	0.73 a	0.33 a
CV	-	3.25%	2.44%	3.77%	3.74%	2.77%	4.65%

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appen.Table- 24: N and P Concentrations in Grains, Straw and Roots of Five Different Varieties of Rice as Affected by Applied Cd (7 mg/kg soil) Over Control

Varieties of Rice			Nitrogen						Phosphorus					
			Grains		Straw		Roots		Grains		Straw		Roots	
Denotations	Name	Treatment combinations	N (%)	t- Value	N (%)	t- Value	N (%)	t- Value	P (%)	t- Value	P (%)	t- Value	P (%)	t- Value
V1	BR-16	V1T0	1.49	5.196 *	1.31	8.660 *	0.70	17.321 **	0.33	5.000 *	0.30	31.000 **	0.28	6.000 *
		V1T1	1.40		1.21		0.60		0.28		0.20		0.22	
V2	BR-15	V2T0	1.59	2.630 ns	1.28	1.890 ns	0.76	1.732 ns	0.33	1.732 ns	0.24	3.464 ns	0.26	1.732 ns
		V2T1	1.54		1.25		0.75		0.32		0.22		0.25	
V3	BR-19	V3T0	1.82	3.464 ns	1.35	1.732 ns	0.85	0.655 ns	0.38	0.655 ns	0.25	0.164 ns	0.30	0.756 ns
		V3T1	1.80		1.34		0.84		0.37		0.25		0.29	
V4	Brridhan-45	V4T0	1.55	1.386 ns	1.27	1.835 ns	0.82	3.464 ns	0.34	0.875 ns	0.26	0.822 ns	0.28	0.918 ns
		V4T1	1.51		1.24		0.80		0.32		0.24		0.27	
V5	Brridhan-29	V5T0	1.65	1.732 ns	1.30	1.732 ns	0.79	3.464 ns	0.35	1.750 ns	0.28	1.387 ns	0.26	0.866 ns
		V5T1	1.63		1.28		0.77		0.33		0.26		0.25	
CV	-	-	1.30%	-	1.62%	-	1.20%	-	5.01%	-	5.85%	-	5.22%	-

* denotes significant at 5% level, ** denotes significant at 1% level, ns denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table- 25: K and Ca Concentrations in Grains, Straw and Roots of Five Different Varieties of Rice as Affected by Applied Cd (7 mg/kg soil) Over Control

Varieties of Rice			Potassium						Calcium					
			Grains		Straw		Roots		Grains		Straw		Roots	
Denotations	Name	Treatment combinations	K (%)	t- Value	K (%)	t- Value	K (%)	t- Value	Ca (%)	t- Value	Ca (%)	t- Value	Ca (%)	t- Value
V1	BR- 16	V1T0	0.79	4.583 *	1.74	5.774 *	0.49	5.000 *	0.85	7.201 *	1.09	24.000 **	0.43	12.851 **
		V1T1	0.72		1.64		0.47		0.74		0.85		0.32	
V2	BR-15	V2T0	0.84	3.464 ns	1.74	2.402 ns	0.47	1.309 ns	0.88	3.464 ns	1.01	3.000 ns	0.50	1.387 ns
		V2T1	0.82		1.69		0.45		0.86		0.98		0.48	
V3	BR-19	V3T0	0.99	3.464 ns	1.83	3.464 ns	0.49	1.000 ns	0.80	2.500 ns	0.98	2.000 ns	0.45	1.890 ns
		V3T1	0.97		1.79		0.48		0.79		0.96		0.43	
V4	Brridhan- 45	V4T0	0.78	1.000 ns	1.78	0.878 ns	0.43	1.387 ns	0.68	1.890 ns	1.30	1.890 ns	0.40	3.464 ns
		V4T1	0.77		1.74		0.41		0.66		1.25		0.38	
V5	Brridhan-29	V5T0	0.82	2.219 ns	1.87	2.000 ns	0.53	1.109 ns	0.78b	1.127 ns	1.40	1.890 ns	0.48	2.000 ns
		V5T1	0.79		1.84		0.52		0.74		1.37		0.47	
CV	-	-	1.89%	-	1.65%	-	5.20%	-	2.90%	-	2.07%	-	3.67%	-

* denotes significant at 5% level, ** denotes significant at 1% level, ns denotes not significant, T0 denotes control and T1 denotes treatment

Appen. Table- 26: Mg Concentrations in Grains, Straw and Roots of Five Different Varieties of Rice as Affected by Applied Cd (7 mg/kg soil) Over Control

Varieties of Rice			Magnesium					
			Grains		Straw		Roots	
Denotations	Name	Treatment combinations	Mg (%)	t- Value	Mg (%)	t- Value	Mg (%)	t- Value
V1	BR-16	V1T0	0.57	6.000 *	0.62	9.707 **	0.30	29.000 **
		V1T1	0.51		0.50		0.20	
V2	BR-15	V2T0	0.68	1.309 ns	0.66	1.000 ns	0.34	1.000 ns
		V2T1	0.66		0.65		0.32	
V3	BR-19	V3T0	0.61	0.571 ns	0.69	1.155 ns	0.32	1.606 ns
		V3T1	0.60		0.67		0.30	
V4	Brridhan- 45	V4T0	0.48	1.732 ns	0.73	2.000 ns	0.33	1.732 ns
		V4T1	0.47		0.71		0.32	
V5	Brridhan-29	V5T0	0.60	1.309 ns	0.76	2.598 ns	0.35	3.464 ns
		V5T1	0.58		0.73		0.33	
CV	-	-	3.04%	-	2.41%	-	3.80%	-

* denotes significant at 5% level,   ** denotes significant at 1% level, ns - denotes not significant, T0 denotes control and T1 dentes treatment

Appen.Table- 27: Cd Concentrations in Grains, Straw and Roots of Five Different Varieties of Rice as Affected by Applied Cd (7 mg/kg soil) Over Control

Varieties of Rice			Cd Conc. in Grains		Cd Conc. in Straw		Cd Conc. in Roots	
Denotation	Name	Treatment combinations	Cd (mg/kg)	t- Value	Cd (mg/kg)	t- Value	Cd (mg/kg)	t- Value
V1	BR-16	V1T0	0.00	-19.053 **	0.11	-67.516 **	0.55	-11.933 **
		V1T1	1.10		14.48		35.00	
V2	BR-15	V2T0	0.00	-92.000 **	0.24	-146.588 **	0.45	-55.825 **
		V2T1	0.031		6.85		37.68	
V3	BR-19	V3T0	0.000	-71.000 **	0.14	-40.658 **	0.42	-65.000 **
		V3T1	0.024		3.79		42.67	
V4	Brridhan- 45	V4T0	0.000	-86.603 **	0.11	-31.143 **	0.73	-128.471 **
		V4T1	0.050		4.80		44.66	
V5	Brridhan- 29	V5T0	0.000	-55.000 **	0.05	-89.956 **	0.57	-49.937 **
		V5T1	0.018		4.02		66.33	
CV	-	-	25.90%	-	4.55%	-	4.55%	-

* denotes significant at 5% level,   ** denotes significant at 1% level, ns denotes not significant, T0 denotes control and T1 dentes treatment

Appen.Table- 28: Fresh Weight, Dry Weight and Percent Yield Reduction of Four Different Test Crops Under study as Affected by Applied Pb (200 mg/kg soil) Over Control

Crop Types			Fresh Weight			Dry Weight		
Denotations	Name	Treatment combinations	FW (g/pot)	t- Value	Reduction (%)	DW (g/pot)	t- Value	Reduction (%)
V1	Lal sak	V1T0	33.73	3.67 ns	4.74	3.03	2.51 ns	4.78
		V1T1	32.13			2.89		
V2	Kalmi sak	V2T0	47.50	2.05 ns	2.56	4.28	2.55 ns	3.13
		V2T1	46.28			4.14		
V3	Grass	V3T0	67.67	2.95 ns	2.42	10.96	2.64 ns	2.85
		V3T1	66.02			10.65		
V4	Spinach	V4T0	43.83	4.43*	27.65	3.18	4.82*	6.59
		V4T1	31.71			2.97		
CV	-	-	13.72%	-	-	2.02%	-	-

* denotes significant at 5% level, ns denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table- 29: N, P, K, Ca and Mg Contents in Straw and Roots of Four Different Test Crops Under Study as Affected by Applied Pb (200 mg/kg soil)

Crop Types		N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
Denotations	Name	Straw	Roots	Straw	Roots	Straw	Roots	Straw	Roots	Straw	Roots
V1	Lal sak	2.79 c	1.39 b	0.34 b	0.20 b	4.79 a	1.50 c	1.27 c	0.42 d	0.85 a	0.20 c
V2	Kalmi sak	3.08 b	1.81 a	0.39 a	0.26 a	3.03 c	1.88 a	1.38 b	0.50 c	0.73 b	0.19 d
V3	Grass	2.51 d	1.19 c	0.32 c	0.16 c	2.25 d	1.51 c	1.33 bc	0.66 a	0.90 a	0.33 a
V4	Spinach	3.50 a	1.80 a	0.28 d	0.16 c	3.43 b	1.78 b	1.63 a	0.64 b	0.85 a	0.26 b
CV	-	1.50%	1.57%	3.75%	5.86%	1.37%	1.60%	2.59%	3.28%	3.13%	5.57%

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appen.Table- 30: N, P and K Contents in Straw and Roots in Four Different Test Crops Under Study as Affected by Applied Pb (200 mg/kg soil) Over Control

Crop Types			Nitrogen				Phosphorus				Potassium			
			Straw		Roots		Straw		Roots		Straw		Roots	
Denotations	Name	Treatment combinations	N (%)	t- Value	N (%)	t- Value	P (%)	t- Value	P (%)	t- Value	K (%)	t- Value	K (%)	t- Value
V1	Lal sak	V1T0	2.88	3.043 ns	1.45	3.46 ns	0.38	2.335 ns	0.24	2.62 ns	4.90	3.600 ns	1.58	3.57 ns
		V1T1	2.79		1.39		0.34		0.20		4.79		1.50	
V2	Kalmi sak	V2T0	3.16	3.179 ns	1.87	2.88 ns	0.45	3.928 ns	0.30	2.75 ns	3.15	3.417 ns	1.97	3.12 ns
		V2T1	3.08		1.81		0.39		0.26		3.03		1.88	
V3	Grass	V3T0	2.57	2.268 ns	1.27	4.11 ns	0.35	3.024 ns	0.18	3.50 ns	2.37	3.328 ns	1.60	3.61 ns
		V3T1	2.51		1.19		0.32		0.16		2.25		1.51	
V4	Spinach	V4T0	3.61	12.851 **	1.88	6.38*	0.31	10.000 **	0.19	5.20 *	3.57	14.000 **	1.86	4.62 *
		V4T1	3.50		1.80		0.28		0.16		3.43		1.78	
CV	-	-	1.07%	-	1.27%	-	3.98%	-	6.40%	-	0.96%	-	1.48%	-

* denotes significant at 5% level, ** denotes significant at 1% level and ns - denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table- 31: Ca and Mg Contents in Straw and Roots of Four Different Test Crops Under Study as Affected by Applied Pb (200 mg/kg soil) Over Control

Crop Types			Calcium				Magnesium			
			Straw		Roots		Straw		Roots	
Denotations	Name	Treatment combinations	Ca (%)	t- Value	Ca (%)	t- Value	Mg (%)	t- Value	Mg (%)	t- Value
V1	Lal sak	V1T0	1.56	1.343 ns	0.47	2.87 ns	0.95	3.969 ns	0.23	2.60 ns
		V1T1	1.27		0.42		0.85		0.20	
V2	Kalmi sak	V2T0	1.45	3.031 ns	0.55	2.87 ns	0.79	3.124 ns	0.22	2.77 ns
		V2T1	1.38		0.50		0.73		0.19	
V3	Grass	V3T0	1.41	3.190 ns	0.72	2.08 ns	0.97	2.524 ns	0.37	3.25 ns
		V3T1	1.33		0.66		0.90		0.33	
V4	Spinach	V4T0	1.71	8.693 **	0.70	10.32 **	0.91	7.181 *	0.31	5.29 *
		V4T1	1.63		0.64		0.85		0.26	
CV	-	-	9.26%	-	3.54%	-	2.83%	-	8.05%	-

* denotes significant at 5% level, ** denotes significant at 1% level, ns denotes not significant, T0 denotes control and T1 denotes treatment

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Appen.Table- 32: Pb Contents in the Straw and Roots of Four Different Test Crops Under Study as Affected by Applied Pb (200 mg/kg soil) Over Control

Crop Types			Pb Conc. in Straw		Pb Conc. in Roots	
Denotation	Name	Treatment combinations	Pb (mg/kg)	t- Value	Pb (mg/kg)	t- Value
V1	Lal sak	V1T0	0.04	-39.344 **	0.81	-69.907 **
		V1T1	230.50		485.90	
V2	Kalmi sak	V2T0	0.04	-70.444 **	0.71	-14.490 **
		V2T1	144.33		255.37	
V3	Grass	V3T0	0.06	-35.821 **	0.63	-30.642 **
		V3T1	34.90		225.60	
V4	Spinach	V4T0	0.07	-16.492 **	0.51	-21.538 **
		V4T1	161.12		276.01	
CV	-	-	9.29%	-	74.85%	-

* denotes significant at 5% level, ** denotes significant at 1% level, ns denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table - 33: Fresh Weight, Dry Weight and Percent Reduction of Four Different Test Crops Under Study as Affected by Applied Cd (15 mg/kg soil) Over Control

Crop Types			Fresh Weight			Dry Weight		
Denotations	Name	Treatment combinations	FW (g/pot)	t- Value	Reduction (%)	DW (g/pot)	t- Value	Reduction (%)
V1	Lal sak	V1T0	35.91	321.300 **	84.15	3.39	113.248 **	85.0
		V1T1	5.69			0.51		
V2	Kalmi sak	V2T0	48.16	3.11 ns	4.56	4.36	2.492 ns	4.75
		V2T1	45.97			4.15		
V3	Grass	V3T0	58.39	2.713 ns	3.92	9.04	0.425 ns	2.95
		V3T1	56.10			8.77		
V4	Spinach	V4T0	33.50	6.148 *	7.95	3.14	4.688 *	7.45
		V4T1	30.83			2.90		
CV	-	-	3.09%	-	-	7.64%	-	-

* denotes significant at 5% level, ** denotes significant at 1% level, ns denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table- 34: N, P, K, Ca and Mg Contents in Straw and Roots of Four Different Test Crops Under Study as Affected by Applied Cd (15 mg/kg soil)

Crop Types		N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
Denotation	Name	Straw	Roots	Straw	Roots	Straw	Roots	Straw	Roots	Straw	Roots
V1	Lal sak	2.08 d	0.99 d	0.16 d	0.11 c	2.61 b	1.15 c	0.76 d	0.22 d	0.64 d	0.12 d
V2	Kalmi sak	3.19 b	2.08 a	0.43 a	0.25 a	3.68 a	1.84 a	1.46 b	0.51 c	0.81 c	0.23 b
V3	Grass	2.25 c	1.25 c	0.28 c	0.18 b	2.17 c	1.41 b	1.23 c	0.73 a	1.03 a	0.38 a
V4	Spinach	3.54 a	1.91 b	0.31 b	0.17 b	3.66 a	1.87 a	1.61 a	0.67 b	0.91 b	0.22 c
CV	-	0.94%	2.56%	4.35%	5.7%	2.89%	2.77%	3.24%	2.80%	2.67%	3.18%

Mean values with the same letter in the same column are not significantly different (p=0.05)

Appen. Table- 35: N, P and K Contents in the Straw and Roots of Four Different Test Crops Under Study as Affected by Applied Cd (15 mg/kg soil) Over Control

Crop Types			Nitrogen				Phosphorus				Potassium			
			Straw		Roots		Straw		Roots		Straw		Roots	
Denotations	Name	Treatment combinations	N (%)	t- Value	N (%)	t-Value	P (%)	t- Value	P (%)	t-Value	K (%)	t- Value	K (%)	t- Value
V1	Lal sak	V1T0	2.85	33.571 **	1.51	12.490 **	0.34	13.750 **	0.25	7.069 *	4.90	33.921**	1.47	7.918 *
		V1T1	2.07		0.99		0.16		0.11		2.61		1.15	
V2	Kalmi sak	V2T0	3.23	1.987 ns	2.18	3.111ns	0.46	3.024 ns	0.29	1.976 ns	3.78	3.464 ns	1.90	2.882 ns
		V2T1	3.19		2.08		0.43		0.25		3.68		1.84	
V3	Grass	V3T0	2.34	3.421 ns	1.32	3.780 ns	0.30	1.147 ns	0.20	2.646 ns	2.23	2.882 ns	1.49	4.000 ns
		V3T1	2.25		1.25		0.28		0.18		2.17		1.41	
V4	Spinach	V4T0	3.67	7.181 *	1.99	8.000 *	0.35	5.500 *	0.29	5.500 *	3.76	10.961**	1.95	23.000 **
		V4T1	3.54		1.91		0.31		0.17		3.66		1.87	
CV	-	-	0.88%	-	2.50%	-	5.28%	-	8.23%	-	2.00%	-	1.88%	-

* denotes significant at 5% level, ** denotes significant at 1% level, ns denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table- 36: Ca and Mg Contents in the Straw and Roots of Four Different Test Crops Under Study as Affected by Applied Cd (15 mg/kg) Over Control

Types of Crops			Calcium				Magnesium			
			Straw		Roots		Straw		Roots	
Denotation	Name	Treatment combinations	Ca (%)	t- Value	Ca (%)	t- Value	Mg (%)	t- Value	Mg (%)	t- Value
V1	Lal sak	V1T0	1.47	80.128 **	0.51	32.505 **	1.04	15.236 **	0.24	35.000 **
		V1T1	0.76		0.22		0.64		0.12	
V2	Kalmi sak	V2T0	1.57	3.745 ns	0.56	3.273 ns	0.85	3.606 ns	0.27	5.500 ns
		V2T1	1.46		0.51		0.81		0.23	
V3	Grass	V3T0	1.28	1.941 ns	0.77	2.982 ns	1.09	3.464 ns	0.42	4.158 ns
		V3T1	1.23		0.73		1.03		0.38	
V4	Spinach	V4T0	1.69	4.619 *	0.74	8.315 *	0.99	5.237 *	0.26	6.928 *
		V4T1	1.61		0.67		0.91		0.22	
CV	-	-	2.26%	-	2.56%	-	2.50%	-	3.82%	-

* denotes significant at 5% level, ** denotes significant at 1% level, ns denotes not significant, T0 denotes control and T1 denotes treatment

Appen.Table- 37: Cd Contents in the Straw and Roots of Four Different Test Crops Under Study as Affected by Applied Cd (15 mg/kg) Over Control

Types of Crops			Cd Conc. in Straw		Cd Conc. in Roots	
Denotations	Name	Treatment combinations	Cd (mg/kg)	t- Value	Cd (mg/kg)	t- Value
V1	Lal sak	V1T0	0.08	- 700 **	0.38	-119.879 **
		V1T1	113.33		198.33	
V2	Kalmi sak	V2T0	0.16	-34.691 **	0.44	- 87.645 **
		V2T1	69.56		278.33	
V3	Grass	V3T0	0.10	-12.921 **	0.29	-91.004 **
		V3T1	22.38		153.67	
V4	Spinach	V4T0	0.12	-19.921 **	0.38	-16.864 **
		V4T1	4.83		27.95	
CV	-	-	25.21%	-	2.51%	-

* denotes significant at 5% level, ** denotes significant at 1% level, ns denotes not significant and T0 denotes control and T1 denotes treatment

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Appen.Table- 38: Correlation Co-efficient Among Some Physico-chemical Properties of Wastewaters Collected from Different Industrial Areas in and Around Dhaka

Parameters	pH	EC	Conductivity	Turbidity	TDS	DO	NO_2^-	NO_3^-	NH_4^+	SO_4^{2-}	HCO_3^-	CO_3^{2-}	TA	PO_4^{3-}	Cl^-
pH	1	-.230	-.209	.026	-.212	-.047	.188	-.453**	-.086	-.466**	.217	.708**	.770**	.417*	.046
EC		1	.995**	.482**	.993**	-.383*	.659**	.401*	.700**	.681**	-.057	-.004	-.035	.423*	.705**
Conductivity			1	.467**	.998**	-.395*	.694**	.410*	.736**	.643**	-.046	.000	-.026	.448**	.727**
Turbidity				1	.461**	-.560**	.529**	.272	.606**	.072	.245	-.053	.096	.347*	.707**
TDS					1	-.389*	.687**	.410*	.738**	.642**	-.042	-.003	-.025	.449**	.727**
DO						1	-.411*	-.197	-.370*	-.151	-.295	-.180	-.341*	-.306	-.370*
NO_2^-							1	.398*	.810**	-.025	.105	.129	.187	.764**	.843**
NO_3^-								1	.591**	-.012	-.165	-.124	-.204	.334	.457**
NH_4^+									1	.035	.142	-.159	-.065	.523**	.961**
SO_4^{2-}										1	-.232	-.104	-.232	-.143	.030
HCO_3^-											1	-.130	.402*	-.037	.194
CO_3^{2-}												1	.851**	.405*	-.095
TA													1	.365*	.024
PO_4^{3-}														1	.558**
Cl^-															1

** Correlation is significant at 0.01 level (2-tailed) and * correlation is significant at the 0.05 level (2-tailed)

Appen.Table- 39: Correlation Co-efficients Among Some Chemical Properties of Wastewaters Collected from Different Industrial areas in and Around Dhaka (**Not included in the manuscript, repetation**)

Parameters	Na	K	Ca	Mg	Zn	Cu	Ni	Pb	Cd
Na	1	.702**	.427*	.217	-.094	-.052	-.069	-.051	.514**
K		1	.129	.031	-.096	-.130	-.034	-.130	.543**
Ca			1	.489**	-.229	-.223	-.229	-.217	-.018
Mg				1	-.125	-.090	-.099	-.091	.103
Zn					1	.464**	.439**	.451**	-.034
Cu						1	.974**	.996**	-.261
Ni							1	.980**	-.258
Pb								1	-.256
Cd									1

Appen.Table- 39: Correlation Co-efficients Among Some Chemical Properties of Wastewaters Collected from Different Industrial Areas in and Around Dhaka

Parameters	Na	K	Ca	Mg	Zn	Cu	Ni	Pb	Cd
Na	1	.702**	.427*	.217	-.094	-.052	-.069	-.051	.514**
K		1	.129	.031	-.096	-.130	-.034	-.130	.543**
Ca			1	.489**	-.229	-.223	-.229	-.217	-.018
Mg				1	-.125	-.090	-.099	-.091	.103
Zn					1	.464**	.439**	.451**	-.034
Cu						1	.974**	.996**	-.261
Ni							1	.980**	-.258
								1	-.256
									1

** Correlation is significant at 0.01 level (2-tailed) and * correlation is significant at the 0.05 level (2-tailed)

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Appen.Table- 40: Drinking Water Standards for Different Parameters

Sl No.	Parameters	Unit	DoE	WHO	USEPA	ISI	CPCB
1	Alkalinity	mg/L	-	-	-	-	600
2	Ammonium	,,	0.5	0.5	0.5	-	
3	BOD (20° C)	,,	2	6.0	5.0	-	-
4	Cadmium	,,	0.005	0.003	0.005	0.01	--
5	Calcium	,,	75	100	100	75	200
6	Chloride	,,	150-600*	500	250	250	1000
7	Chromium (total)	,,	0.05	0.05	0.05	-	-
8	COD	,,	4	10	4	-	-
9	Conductivity	μS/cm	-	-	-	-	2000
10	Copper	mg/L	1	1	1.3	0.05	1.5
11	DO	,,	6	4 - 6	4 - 6	-	-
12	EC	μS/cm	2000	-	300	-	-
13	Hardness (as CaCO$_3$)	mg/L	200-500	500		300	600
14	Lead	,,	0.05	0.01	<0.05		
15	Magnesium	,,	30-35	50	-	30	100
16	Nickel	,,	,,	,,	,,	,,	0.05
17	Nitrite	,,	-	-	-	-	0.2
18	Nitrate	,,	10	10	10	45	100
19	Total alkalinity as CaCO3	,,	25-400	-	-	-	600
20	pH	,,	6.5-8.5	6.5-8.5	6.0 – 8.5	6.5-8.5	6.5-8.5
21	Phosphate	,,	0.6	0.1	0.1	-	-
22	Potassium	,,	12	1.2	1.5	-	-
23	Sodium	,,	200	6.5	10	-	-
24	Sulfate	,,	400	100	100	150	400
25	Total dissolved solids (TDS)	,,	1000	500	500	-	-
26	Turbidity	NTU	10	-	-	10	-
27	Zinc	mg/L	5	-	5.5	5.0	15

Appen.Table- 41: Tolerable Total Heavy Metal Concentrations in Soils

Element	mg/kg soil	Element	mg/kg soil
Zn	300	Cr	100
Cu	100	As	20
Ni	50	Sb	5
Pb	100	Be	10
Cd	3	B	25
Hg	2	Mo	5
Co	50	Se	10

(Source: Kloke, 1980)

Appen.Table- 42: Ideal Values for Pb, Cd and Hg in mg/kg Fresh Substance.

Vegetables/crops	Lead	Cadmium	Mercury
Wheat grains	0.3	0.1	0.03
Rye grains	0.4	0.1	0.03
Potato	0.25	0.1	0.02
Turnip	2.0	0.1	0.05
Spinach	0.8	0.5	0.05
Leafy vegetables	0.8	0.1	0.05
Shoot vegetables	0.5	0.1	0.05
Cellery	0.25	0.2	0.05
Root vegetables	0.25	0.1	0.05
Fruit vegetables	0.25	0.1	0.05
Fruits	0.5	0.05	0.03

(Source: Horak, 1996)

Appen.Table- 43: FAO Recommended Maximum Concentration of Trace Elements in Irrigation Water

Trace element	Maximum concentration (mg/L)
Aluminum (Al)	5.0
Arsenic (As)	0.10
Beryllium (Be)	0.10
Cadmium (Cd)	0.01
Chromium (Cr)	0.10
Cobalt (Co)	0.05
Copper (Cu)	0.20
Fluorine (F)	1.0
Iron (Fe)	5.0
Lead (Pb)	5.0
Lithium (Li)	2.5
Manganese (Mn)	0.20
Molybdenum (Mo)	0.01
Nickel (Ni)	0.20
Selenium (Se)	0.02
Vanadium (V)	0.10
Zinc (Zn)	2.0

Appen.Table - 44: FAO/WHO, 2001 Standard Limit Values for Vegetables and Rice Grains (FAO/WHO, 2001)

Heavy metals	Standard limits for heavy metals mg kg^{-1} dry wt
As	1.0
Cd	0.20
Pb	0.30
Zn	50.0
Cr	1.0
Cu	10.0
Ni	0.02-2.7

Appen.Table- 45: Guideline for Safe Limits of Heavy Metals in Plants (Anita *et al.*, 2010)

Standards (μg g^{-1})	Cd	Cu	Pb	Zn	Ni	Cr
Indian Standard	1.5	30	2.5	50	1.5	20
European Standard	0.2	-	0.30	-	-	-

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