INTRODUCTION

Pollution has become the skull and crossbones of modern civilization. Industrialization is the main cause which makes the problem even worse. But man cannot do without industrialization, so the measures to be taken to control pollution become very important.

There are many pollutants, which make the life on earth miserable. Heavy metals are a group of such pollutants. Though Nieboer and Richardson (1980) are of opinion that, the term 'heavy metal' should be abandoned, it is followed in the present work, because of the world wide acceptance and clarity of the term. Examples of heavy metals are Cd, Cr, Co, As, Cu, Fe, Hg, Mn, Mg, Mo, Ni, Pb, Sn, Sb, Zn etc. Their atomic number varies from 22-92, and they have a density greater than 5 in the
elemental form. Among these, Cu, Fe, Mn, Mg, Zn, etc. are beneficial to plant life in micro quantities since they serve as trace nutrients. But even they become toxic at higher concentrations (Foy 1974; Clement et al., 1974; Tadano, 1975; Chaney and Giordano, 1977). But metals like Hg, Cd, Cr, As, Ni, Pb, Sn, etc. are in no way good for living organisms. Moreover, they cause many serious biological abnormalities (Bergh, 1952; Foy, 1974; Clement et al., 1974; Tadano, 1975; Chaney and Giordano, 1977; Judith et al., 1978; Takkar and Mann, 1978; Baishnab and Prasanna, 1980; Balch et al., 1991; Barcellos et al., 1991; Boon and Soltanpour, 1992; Huebert and Jennifer, 1992).

One very important and troublesome feature of the heavy metals is that, once they have entered the atmosphere, they are there to stay, in one form or another.

All soils, even uncontaminated ones, contain heavy metals as a result of weathering of their parent rock material (Keeks and Miettinen, 1970; Pierce et al., 1970; Anderson, 1979). Volcanic activities, geothermal vents etc. also serve as natural sources of heavy metals. But man’s activities make the problem more fierce. Man made sources of heavy metal pollution include, mining works, metal plating, pesticides, detergents, nuclear power plants, water pipes, industrial effluents, domestic wastes, sewage sludges etc. These pollutants alter the natural qualities of air, water and soil and make them highly contaminated. Even, air polluted with heavy metals can behave as a source of heavy metals for the soil, as they can reach the soil by sedimentation.
As man grabs more and more industrial achievements he is prone to more severe pollution problems, since it is an inevitable part of industrialization. The industrial, power generating and transport activities of modern world involve chemical and physical transformations of matter of great diversity and stupendous scale. Many such materials are disposed into the general environment. Heavy metals form a very large part of these out puts. The toxicity of them depends on their availability in the environment.

Plants are the chief victims of soil pollution, as they live in direct contact with the soil. Through them the whole food chain will be affected and the impact spreads in all the trophic levels. One common feature of the heavy metals in relation to the biological world is that, in excess quantities, they are poisonous and can cause death of many living organisms. After the entry of these heavy metals into the soil, they get incorporated into the system of the plants, and above a particular concentration they become toxic (Bergh, 1952; Foy, 1974; Clement et al., 1974; Tadano, 1975; Chaney and Giordano, 1977; Judith et al., 1978; Takkar and Mann, 1978; Baishnab and Prasanna, 1980; Balch et al., 1991). Influence of heavy metals on nucleic acid synthesis, cell division and protein contents was studied by Siegel (1974); Vaulina et al. (1978); Maitra and Mukherji (1979); Wickliff (1980) and Nag et al. (1981).

Yousufsaig (1991) has reported that the road side dust from a region at Karachi, where traffic density was very high, contained
high concentrations of heavy metals like Pb, Zn, Mn, Cu, Cd etc. Contamination of the soil, water and plants through the heavy metals is studied in detail by many researchers (Merry and Tiller, 1978; Lacerda and Abrao, 1984; Kavetskii et al., 1985; Aleshchukin, 1989; Long and Davis, 1989; Dickman et al., 1990; Badret et al., 1990; Xuexun and Guolinhai, 1991; Govindarajan and Rao, 1992; Benninger et al., 1993; Hulina et al., 1993; Joseph and Srivastava, 1993; Muench, 1993; Otte and Wijte, 1993; Pip, 1993; Tariq et al., 1994; Venkateswarlu et al., 1994; Zrodlowski, 1994). Some other works in relation with metal toxicity need special mention are - Gorham and Goodon (1963); Wu et al. (1975); Foy et al. (1978); Woolhouse (1983); and Kotangale et al. (1984). Klein (1972) reported that heavy metals like Hg, Cd, Zn, etc. are more abundant in industrial areas than on residential or agricultural areas. Little and Martin (1972) studied the contamination of vegetables near a smelting complex. Woolhouse (1983) reported the toxicity and tolerance response of plants to heavy metals. Gorham and Gordon (1963) observed how the smelter pollution affect aquatic vegetation. Earnst (1972); Takijema et al. (1973); Thornton and Webb (1979) and Marilyn (1975) are some others who have worked out the pollution caused by smelting industries.

Broman et al. (1991) and Sudhakar et al. (1991) have studied the heavy metal toxicity in Mytilus and algae respectively. Xuexun and Guolinhai (1991) worked out the problem of heavy metal pollution in the soil and plant in Tianjin waste water irrigated area and reported that, the critical values of 6 heavy metal elements in
soil are - Hg- 0.5 ppm, Cd- 1.2 ppm, Pb-20 ppm, Cu-160 ppm, Zn-500 ppm and Ni-30 ppm.

In the present work an attempt has been made to study the impacts caused by three heavy metals - Hg, Cd, and Zn on 3 Solanaceous plants.

Mercury is considered as a very deadly pollutant. The main sources of mercury pollution are the chlor-alkali plants, seed dressings, industrial discharge, aerosols, mining, pesticides, barometers, vacuum pumps, liquid seals etc. It is also used as an electrical contact. Mercury can form amalgam with all metals except iron and platinum. Gold/mercury, Silver/mercury, Tin/mercury amalgams are used in dentistry. Mercury is used in the extraction of Gold. All these above sources constitute the major causes of Hg pollution (Treshow, 1970; Gilmour and Miller, 1973; Wallin, 1976; Sastry, 1982; Srivastava and Singh, 1990; Meij, 1991; Mukherjee, 1991; Jing and Terry, 1992; Lenka et al. 1992). Naturally, trace components of Hg occur in many minerals (Pierce et al., 1970; Anderson, 1979). The principal ore of mercury is HgS - Cinnabar.

Man’s activities constitute a major source of Hg pollution in the environment. The ‘Minamata’ episode in Japan during 1953-60 provides the most clear cut example of a disaster caused by industrial pollution (Anon, 1970). Many people died, babies with genetic disorders were borne and many became affected for life. The poisoning occurred as a result of eating mercury contaminated fish and shell fish from the Minamata Bay. The patients had
suffered from vision disorders, loss of muscular co-ordination and cellular degeneration in the cerebellum, mid brain and cerebral cortex, which led to spasticity, rigidity, stupor and coma and ultimately to death (Goldwater 1971; Fujiki, 1972). The source of the pollution was a single plastic factory, which discharged its mercury rich effluents, into the near by water body. In the factory mercury was not even included in its routine sampling of effluents. It became clear only after the works of Jensen and Jernelov (1969) that micro organisms can convert the inorganic mercury into the deadly methylated form, which caused the disaster. Japan reported a second and third episodes of Minamata disease in 1964-1965 and 1973.

In 1972, Iraq too witnessed a very tragic incident of mercury poisoning. The farmers in Iraq, ate the mercurial fungicide treated seeds, meant for sowing. When the authorities took notice of this, they announced that all should dispose off the seeds, otherwise they would be punished. The frightened farmers disposed the seeds into the near by water body. Bakir et al. (1973) reported that, the combined effect of this blunder was the loss of 5000 - 50,000 lives and the permanent disability of more than 1,00,000 people.

The organic mercurials are the most toxic forms of Hg, especially \( \text{CH}_3 \text{Hg} \). Hg-C bond is a comparatively stable one, so the alkyl mercury can be retained in the cells for a long time. Elemental Hg is fairly inert and non-toxic. But Hg or its salts can be converted to methyl mercury by micro organisms (Jensen and
Jernelov, 1969; Wood, 1972; Suzuki and Hatanka, 1975; Jackson, 1993). This conversion is facilitated by CO(II) - containing vitamin B₁₂ coenzyme. A CH₃ - group bonded to CO(II) on the coenzyme is transferred by methycobalamin to Hg²⁺ yielding CH₃ Hg²⁺ or (CH₃) Hg⁺. Mercury is capable of undergoing biological magnification by a factor 10³ or more as it passes up the food chain. It is worth noticing that the contaminated sediments of river and lakes will continue to discharge methyl mercury to the water body for many years to come. Ramel (1974) reported that half life of methyl mercury is 70-days and even at very low concentrations it can cause genetic disorders.

Mercury and its derivatives can interact strongly with - SH and -S-S- groups in proteins and other biological molecules (Passow et al., 1961; Vallee and Ulmer, 1972; Bhandal and Kaur, 1992). All heavy metals have affinity for sulphur containing ligands (Venanzi, 1991). Mercury too share this property, and so it can act as an enzyme inhibitor. Metalloenzymes contain metals in their structure. Their action is inhibited when one metal ion of a metalloenzyme is replaced by another metal ion of similar size and charge like, Hg, Cd, Zn or any other heavy metal. This will lead to heavy metal toxicity.

Studies by Furlan and Kosta (1972) revealed that how mercury pollution affected the vegetation near a mercury distillation plant at Idrija. Among others who studied deeply the effect of mercury pollution on plants and environment need special mention are Gorham and Goddon (1963); Antonovics et al. (1971); Puermer and Siegel (1972); Furlan and Kosta (1972); Haney and Lipsey.
(1973); Wu et al. (1975); Hashiguchi et al. (1976); Tompkins and Blinn (1976); Dobrowski et al. (1977); Lepp (1977); Foy et al. (1978); Rao (1979); Rajamani and Madhavakrishna (1982); Babu and Nandakumar (1982); Sastry (1982); Woolhouse (1983); Kotangale et al. (1984); Rashmi and Panigrahi, (1994); Zrodowski, (1994). A recent episode of 'Minamata' disease was reported by Korogi et al. (1994). Reduction in the growth rate of algae as a result of mercury toxicity was reported by Harris et al. (1970); and Overnell (1975). Mohapatra and Panigrahi (1991) found that at high Hg concentration a significant decrease in chlorophyll content and primary production was produced in mulberry plant. Morphological and physiological disorders of plants caused by Hg pollution have been reported by many workers Strognonov (1964), Harris et al. (1970); Levitt, (1972); Mayber and Gale, (1975); Misra, (1984). Mercury induced inhibition of chromosomal disjunction during gamete formation has been reported by Ramel (1974). Mercury toxicity in algae has been extensively studied by De Filippis and Pallaghy, (1976); Geike (1977); Misra et al. (1985). The effect of mercury on seed germination was reported by Loo and Tang, (1945); Dickey and Ark (1949); Crosier (1950); Prota (1960); Passow and Rothstein (1960); Robson and Fenn (1961); Dempsey and Chandler (1963); Morgan et al. (1966); Stonier et al. (1968); Hinsely et al. (1971); Sheigh and Barber (1973); Mukherji and Ganguli (1974); Singh and Mukhiya (1980); Edward Mrozek (1980); Mhatre and Chaphekar (1982); Misra and Misra (1984); and Shanti Swarup Sharma (1985). Assache and Broeck (1964) studied the adverse effect of organic mercurials on
seed germination. Others like Banerji and Kumar (1979); Jain (1981); Veer and Lata (1987) also have studied heavy metal toxicity in plants and soils.

Natural occurrence of cadmium is in association with zinc minerals (Arey and Tiagi, 1985). Its mineral ore is sulphide (CdS). The 'itai-itai' disease occurred in Japan in which bones of the patients became fragile, was a result of cadmium toxicity. It was caused by food contamination from a local industrial source (Emmerson, 1970). As cadmium concentration was very high in the body tissues of the patients, a search for its source revealed high levels of cadmium in the local rice and soybean crops. The cadmium had originated from a nearby lead-zinc mining and smelting complex. The stream which irrigated the crop field got contaminated from it, which in turn resulted in the contamination of the crop. Another incident of 'itai-itai' occurred in Japan near Bondai, in which case too the source of cadmium was a nearby zinc smelter. All these incidents point to the fact that trace amount of cadmium is always associated with zinc minerals. Since plants require Zn as a micronutrient, along with Zn they absorb Cd too and Cd gets concentrated in the plant body.

The chief sources of environmental cadmium include burning of diesel and heating oil, phosphate fertilizers, sewage sludge, car tyres, street dust, smelting industries (Koepppe, 1977). Cadmium finds a variety of applications in electroplating, rockets, missiles and supersonic aircrafts, pigments, batteries, poly vinylchloride, stabilizer, fungicides and antihelminthics.
Cd is a carcinogen. It can cause kidney damages, anemia etc. in human beings. Symptoms of cadmium toxicity include hypertension, respiratory disorders, damage to liver and kidney etc.

Cadmium is less toxic to plants than methyl mercury. Toxic levels of cadmium in plants produce chlorosis and reduced plant growth. Smoking and food are the major source of cadmium for public. Cigarette tobacco contains about 1 ppm Cd. It is found that leafy vegetables take up more cadmium than root crops. But at times, the contribution of cadmium from root crops becomes significant, because of the large proportion of root crops in the daily diet. Cadmium accumulation in the leaves of cabbage and tobacco seedlings was reported by Wagner (1984). Cadmium can inhibit enzymes, because of its affinity for SH groups of the enzymes. Cadmium uptake by plants has been studied by Hatch et al. (1988); Hsieh (1990); Lin and Hsu (1990); Jing and Terry (1992); Salim et al. (1992); Taylor et al. (1992); Reboredo (1992). Since Cd$^{2+}$ binding, proteins can also bind Zn$^{2+}$, Cd detoxification occurs in animals (Webb, 1975; Richards and Cousins, 1975). Zinc smelting is a main source of cadmium for the soil (Ernst, 1972; Takijema et al., 1973; Thornton and Webb, 1979). Binding of proteins to Cd is reported by Casterline and Yip (1975); Casterline and Barnett (1977); Weigel and Jager (1980) and Bartlof et al. (1988).

Low concentrations of cadmium are reported by Paul and Pillai (1983) in Periyar river water in Kalady to Alwaye and Varapuzha to Vayur. The river water around the industrial area, from Alwaye to Varapuzha, contained slightly higher levels of
Though at lower concentrations cadmium is relatively nontoxic but at higher concentrations it causes toxicity to animals and plants (Vallee and Ulmer, 1972; Bazzaz et al., 1974; Huang et al., 1974; Hamppe et al., 1976; Bazynski et al., 1980, Wickliff, 1980; Pahlsson, 1989). Cadmium inhibition of mitochondrial electron transport and respiration and enzyme activities are reported respectively by Miller et al. (1973); Lee et al. (1976); and Weigel and Jager (1980). Some phosphatic fertilizers usually contain small traces of cadmium (Swaine, 1962).

Cadmium related decrease in the dry weight and carbohydrate concentration has been reported by Greger and Bertrud, (1992 Reboredo (1992) found that in Halimione portulacoides (L.), in 75% of the cases cadmium content of leaves was higher than the root content. Inhibition of root growth and reduction in the dry weight of rice as a result of cadmium toxicity was observed by Muramato (1989). Cadmium induced changes in the plant metabolic cycle and metabolite contents have been variously studied by Bazzaz et al. (1974); Root et al. (1975); Beauford et al. (1977); Pfluger and Widemann (1977); Bazynski et al. (1980); Frossard and Moeri (1986); Greger and Lindberg (1986); Schlegel et al. (1987); Sheoran et al. (1990); Greger et al. (1991). Cabrera et al. (1988) reported that CdCl\(^+\) ions displayed a lower rate of uptake than Cd\(^{2+}\). Although CdCl\(^+\) ions display a lower rate of uptake than Cd\(^{2+}\), the effect of chloride is to increase the bioavailability of the metal. Sheoran et al. (1990) found
that $\text{Cd}^{2+}$ was more inhibitory than $\text{Ni}^{2+}$ at all concentrations.

Bram and Anthony (1988) are of opinion that soils subjected to an episodic contamination with soluble cadmium at levels less than 3.0 ppm could be used for grain only after the 6th year.

Burton and Morgan (1984) studied the influence of heavy metals upon the growth of Sitka-spruce in South Wales forest. They found that the levels of cadmium in shoots increased with the increase of cadmium in the soil. Increase of cadmium in shoots decreased plant shoot yields. Root length was affected when the cadmium in soil became more than 2.5 ppm. Influence of lead, cadmium and nickel on the growth of *Medicago sativa* L. was studied by Taylor and Allinson (1981). They found that cadmium can significantly decrease the yield of the plant. In CdCl$_2$ treated plants of *Arachis hypogaea*, considerable inhibition of germination occurred (Satakopan and Rajendran, 1989). Cadmium accumulation in soybean seeds has been noted by Domini et al. (1981). The effect of cadmium on photosynthetic process has been studied by Baszynski et al. (1980); Jastrow and Koeppe (1980); Clijsters and Van Assche (1985); Baszynski (1986); Wozny et al. (1990). According to Wiegel (1985) cadmium inhibits the reactions of Calvin Cycle, thereby inhibiting the photosynthesis. It probably may be inhibiting RUBP carboxylase activity. Ernst (1980); Stiborova et al. (1986 a, b) also share the same view. Stiborova (1988) found that RUBP can be a target for the toxic action of $\text{Cd}^{2+}$ on photosynthesis because the other photosynthetic processes are influenced only by higher $\text{Cd}^{2+}$ concentrations. Greger and Orgen (1991) reported Cd induced inhibition of CO$_2$ assimilation of the leaves and isolated...
protoplasts of sugar beet. Among others who did a detailed work on cadmium pollution the following personell need special mention (John et al., 1972; Koepppe, 1977; Yuran and Helen, 1986; Mathur et al., 1987; Van et al., 1988; Wolterbeck et al., 1988; Gries and Dieter, 1989; Singh and Kees, 1989; Badr and Azza, 1990 (1991); Lin et al., 1990; Liv et al., (1991); Gupta and Jaswanth, (1992); Hattori, 1992; Keshan and Mukherji, 1992; Salim et al., 1992a, b; Frank and Tamova, 1993; Merian, 1993; Sweet, 1993; Fargasova, 1994).

In nature zinc is of wide occurrence, mainly as zinc blend (ZnS), Zincite (ZnO), Smithsonite (Zn CO₃) etc. Zinc forms about 0.004% of the earth's crust and ranks 25th in the order of abundance. The chief manmade sources of zinc include mining, smelting and refining works, soil application of sludge and slurries, use of pesticides, industrial and domestic wastes etc. Zinc finds a variety of applications in metal plating, alloys, catalysts, tyres etc.

Zinc is an essential trace nutrient for both plants and animals. But at higher concentration it causes many disorders in plants and animals. Zinc is usually found in the soils adjacent to roads, the sources are the tyres and lubricant oils (Lagerwerff and Specht, 1970). Domestic and industrial wastes always contain a large amount of zinc in them (Le Riche, 1968 Berrow and Webber, 1972; ). Urban and industrial pollution resulted in the accumulation of Zn in the sediments of lakes (Shimp et al., 1970; Collinson and Shimp, 1972; Pita and Hyme,
1975). Zn toxicity is greatest on acidic mineralised soils.

Zinc inhibition of plant growth, especially root growth may operate on cell elongation (Wainwright and Woolhouse, 1977). As in the case of other heavy metals here the inhibition of root growth is not accompanied by cell content loss (Wainwright and Woolhouse, 1975, 77). Inhibition of root growth as a result of Zn toxicity is reported by Bradshaw (1952); Broker (1963); Gregory and Bradshaw (1965); Antonovics et al. (1971); Wainwright and Woolhouse (1975). Turner and Marshall (1972) have reported that subcellular fraction of the roots of Agrostis tenuis can accumulate zinc.

The uptake and distribution of zinc by plants has been studied by many (Rathmore et al., 1970; Mathys, 1977; Sieghardt, 1990). Takkar and Mann (1978), studied the toxic levels of Zn on maize and wheat and found that for maize 11 ppm Zn in soil and 81 ppm Zn in plant, and for wheat 7 ppm Zn in soil and 60 ppm in plant was toxic. Judith et al. (1978), in their study on corn, grown in zinc rich soil found severe chlorosis and stunting of the plants.

Cakmark and Marschner (1986) reported zinc induced reduction, in plant growth, yield and metabolic rate. Photosynthesis was also affected (Robson and Pitman, 1983). Yousufzai (1991) proved that road side dust in a metropolitan city of Karachi contained 112-2215 ppm Zn in it. Much work on zinc toxicity has been done worldwide (Chapman et al., 1939; Hsu and Miller, 1965; Machold and Stephan, 1969; Ambler et al., 1970;
Leaf chlorosis due to zinc toxicity is reported by Chapman et al. (1939); and Aragwala et al. (1977). This may be due to the inhibition of the translocation of Fe from root to shoot (Amber et al., 1970; Agarwala et al., 1977). There is a view that the chlorosis due to Zn toxicity may arise from Fe/Zn competition for an iron requiring step in the biosynthesis of chlorophyll (Hsu and Miller, 1965; Machold and Stephan, 1969; Duggan and Gassman, 1974). Goldschmidt (1962) suggests that the almost identical radii of the hydrated ions of Zn$^{2+}$ and Fe$^{2+}$ ($0.083$ nm) may be the reason for this.

Lingle et al. (1963) found that zinc was the strongest interfering ion that depressed Fe uptake of the plants and also interfered with translocation of Fe to the tops. Greger and Kautsky (1991) in their studies on the effect of Cu, Pb and Zn on Potomogoton species, found that all the 3 metals reduced biomass production and the toxicity of the metals shown to decrease as follows Zn$>$Cu$>$Pb. Stiborova and Leblova (1984) showed that the heavy metals - Cu$^{2+}$, Pb$^{2+}$, Zn$^{2+}$ and Cd$^{2+}$ can inhibit the isoenzymes of maize. Here the heavy metal effect can probably involve the interaction with SH groups of PEPC. Bruce et al. (1978) showed that Mn, Zn, Co and Cd have inhibitory effects on tomato seedlings. Rothenberger and Galitz (1977) are of opinion that low concentrations of Cd and Zn slightly stimulate.
the seedling growth of some grasses, but higher concentrations retarded the growth. Maze (1919) and Sommer (1928) showed that zinc is essential for plant growth. Kanwar (1964); Patel et al. (1976) and Saxena and Singh (1970) reported that by applying low amounts of zinc, yield can be increased. Aery and Sarkar (1991) observed that as soil concentration of zinc increased beyond 25 μg g⁻¹ a steady drop up to 90% over the control in different parameters observed. Gupta and Singh (1972); Patel et al. (1976); Ohki (1975, 76, 78) are some others who have reported yield reduction in plants treated with high zinc concentration. According to Aery and Sarkar (1991) the decrease occurred in the growth of the plants treated with higher concentrations of Cd and Zn may be due to the reason that the stressed plants have to spend more energy for their survival in the hostile environment, which otherwise could be used for their growth. This leads to growth reduction. Others like Van et al. (1988); Hattori (1992); Badr and Azza (1990, 1991) have also studied the effect of Zn and Cd toxicity on lower and higher plants.

The reduction in yield, nodulation, leghaemoglobin, total nitrogen, protein nitrogen, and RNA content at 1.1 ppm Zn is reported by Janardhan Reddy and Rao (1978). According to Shive (1941), the toxic doses of a particular element may cause the deficiency of other elements. Fredman (1977) found that corn grown in an abandoned zinc mining area had stunted growth and chlorotic appearance.

There are many ways through which soil pollution by heavy metals occur. Application of sewage sludges to land has become
the main cause for metallic contamination of soil. Along with the sewage sludge excess organic matter is also added to the soil, which increases the distribution of the metals. Soil pH also affects the metal’s mobility.

When the waste lands are used for the controlled dumping of domestic refuse, or sewage sludge the land becomes reservoirs of metals. These areas will be used for vegetable growing or building flats. During these operations, the metals get well mixed with the soil and when it rains, the metals will leach out and cause water pollution. In addition, the vegetables growing on these areas will also be affected. Moreover when the leached out metals reach the water body, they will highly pollute the plants irrigated with the water. In addition to this all the water bodies are polluted with industrial effluents most of which include many deadly poisonous heavy metals. The combined effect of all these activities make the soil and water highly contaminated, which in turn will cause the contamination of the plants growing on these areas. When the plants are polluted, the whole food chain will be affected and the impacts spread in all trophic levels. Since many heavy metals are capable of biological amplification, the problem becomes more severe.
II. MATERIALS AND METHODS