The volume of waste generated and problems with safe disposal make coal combustion by-products a menace to public health and environment. The rate of CCPs generation has been steadily increasing and is also predicted to ascend in the next two decades, mainly due to the intensification in coal usage for energy production (WEC, 2007). The rising Asian economies and the already developed nations like United States of America and Australia are also projected to increase their energy needs.

Coal is derived as geological processes apply pressure to peat over time; it is transformed into the following types based on their organic maturity (WCI, 2009):

- **Lignite (brown coal)** - is the lowest rank of coal and used solely as fuel for steam-electric power generation.

- **Sub-bituminous coal** - properties range from those of lignite to bituminous coal and are used primarily as fuel for steam electric power generation.

- **Bituminous coal** - a dense coal, usually black, sometimes dark brown, used primarily as fuel in steam-electric power generation, with substantial quantities also used for heat and power applications in manufacturing and to make coke.

- **Anthracite** - the highest rank of coal and is a harder, glossy and black coal used primarily for residential and commercial space heating.

Coal-fired power stations generate a number of by-products during the combustion of coal. Coal is usually burnt in a pulverized fuel furnace, resulting in two major types of ash products (CCPs) – the fly ash (FA) and the bottom ash (BA). The FA, which is recovered from the flue gas, has fine texture and is the major portion (90%) of ash produced. The remainder is collected at the bottom of the furnace as BA (coarser than
Apart from these two ash products, two other by-products - fluidized bed combustion (FBC) ash and flue gas desulphurization (FGD) ash are produced as part of Clean Coal technologies, mainly to trap sulphur oxides (SOx) produced during the combustion of high sulphur (S) containing coal (Stout et al., 1998). The use of Coal Combustion Products (CCPs) as a soil amendment has been an on-going area of investigation in many countries that produce coal and also use coal as an energy source. Following a brief overview of the types of CCPs, volume of production and their industrial, agricultural and environmental applications, the review focuses on the role of CCPs in managing the bioavailability of nutrients such as nitrogen, phosphorus, sulphur and calcium, and heavy metals such as cadmium, lead and mercury in relation to enhancing soil chemical fertility and mitigating metal contaminated soils. Coal reserves are available in almost every country worldwide, with recoverable reserves in around 70 countries. At current production levels, proven coal reserves are estimated to last 122 years. In contrast, proven oil and gas reserves are equivalent to around 42 and 60 years at current production levels, respectively. This indicates the potential continuing dominance of coal in energy production in the most successful industrial nations like United States, China, India, Australia and South Africa, where the coal power plants contribute over 50% to the energy needs of these countries. Global coal consumption is expected to increase at an average rate of 1.7% per year until 2020 and share of coal in world primary energy demand will remain stable at about 25% until 2020 (IEA, 2012). Although the coal industry welcomed the progress made in the Copenhagen summit (2009), it urged the governments to be more ambitious on climate change and work quickly to reach a legally binding agreement (WCI, 2009). This will eventually drive the industrially
powerful countries to invest on clean coal technologies and ensure effective carbon capture and storage. The clean coal technologies include the safe disposal and beneficial utilization of post combustion products.

Coal is the largest contributor to global CO$_2$ emissions from energy use (41%), and its share is projected to increase substantially in years to come. The use of coal also has many adverse impacts. Coal mining historically has been a dangerous occupation, with workers toiling under often inhuman conditions. Mining has leached hazardous chemicals into water sources and destroyed forests and habitats. Entire mountains in some locations have been lost due to strip mining. While regulations on power-plant emissions have reduced air pollution significantly (particularly in Europe and the United States), there is now a much bigger, global threat from increased coal use. Emissions of CO$_2$ from coal combustion have been identified as a primary culprit in increasing atmospheric CO$_2$ concentrations, strongly affecting the world’s climate (IPCC, 2001a). Climate change mitigation efforts will require significant reductions in global CO$_2$ emissions, especially from coal use. India’s CO$_2$ emissions from fossil fuels have been increasing at a compounded annual growth rate of 5% from 1990 to 2004 (Marland et al., 2007), in comparison to ~5.4% for China, ~1.6% of US, and ~1.8% globally. More recently (from 2000 to 2004), India’s emission growth rate has decreased to 3.8%, while the United States’ is down to 0.3%; however, the rates for China and worldwide emissions have increased dramatically to 10.7% and 3.2%, respectively (Marland et al., 2007). Despite being the fourth largest emitter of CO$_2$ emissions worldwide, India’s total emissions in 2004 were still about 4.5 and 3.7 times smaller than U.S. and China emissions, respectively. Furthermore, India’s carbon emissions on a per capita basis in 2004 were
almost one-sixteenth the comparable figure for United States and one-third the figure of China.

The Fly-ash mission was commissioned in 1994 with the Department of Science and Technology as the nodal agency and the Technology Information and Assessment Council (TIFAC) as the implementing agency. The Ministry of Environment and Forests, Govt. of India, Ministry of Power, Thermal Power stations, R&D Institutions and Industry together have launched a Technology Project in Mission Mode (TPMM). Their focus is on the demonstration of coal ash related technologies for infusing confidence and thus ensuring large scale adoption. Fly ash utilization has great potential to lower green house gas emissions by decreased mining activities and reducing Carbon dioxide production during manufacture of materials that can be substituted by fly ash. Fly ash can substitute up to 66% of cement in the construction of dams. It is also used as a pozollanic substitute for cement in Roller Compacted Concrete dams-an innovative dam technology developed as a result of efforts to design more economical concrete dams that could be constructed rapidly with designed performance. Fly ash in R.C.C. is used not only for saving cement cost but also for enhancing strength and durability. Replacement levels of fly ash primarily Class F, ranges from 30-75% of total cement material. Fly ash can also be used in Portland cement concrete to enhance the performance of the concrete. Portland cement is manufactured with Calcium oxide, some of which is released in a free state during hydration. As much as 20 pounds of free lime is released during the hydration of 100 pounds of cement. This liberated lime forms the necessary ingredients for reaction with fly ash silicates to form strong and durable cementing compounds thus improving many of the properties of concrete. Typically 15-30% of the Portland cement is replaced...
with fly ash. This results in net reduction in energy use and greenhouse gas and other emission.

2.1. Types of coal combustion by-product

The Ash Development Association of Australia has recently updated the definitions of CCPs as follows (Seshadri et al., 2010):

2.1.1. Fly ash (FA) - the non-combustible oxidized elements, light to mid-grey in colour, with sphere-shaped particles ranging in size from less than 1 μm to 100 μm that exit the combustion chamber in the flue gas and is captured using electrostatic precipitators, filter bag houses or wet scrubbers. FA has typical pozzolanic characteristics (siliceous, or siliceous and aluminous material).

2.1.2. Bottom ash (BA) - agglomerated ash particles formed in pulverized coal furnaces that are too large to be carried into the flue gas stream and impinge upon the furnace walls or fall through open grates to an ash hopper at the bottom of the furnace. Bottom ash is typically grey to black in colour, is quite angular, and has a porous surface structure.

2.1.3. Fluidized bed combustion (FBC) ash – is formed when fine coal is burnt in the presence of crushed limestone as abiding material in fluidized form. The FBC is a technology employed to limit the amount of S released into the atmosphere while burning S-rich coal. Sulphur dioxide (SO₂) released during combustion is converted to calcium sulphate (CaSO₄) through its reaction with the calcined limestone. Fluidized bed furnaces burn coal at lower temperatures (815 - 870°C) than the conventional coal fired furnaces.
(1400 -1600°C). The chemical reactions involving the limestone charge in a fluidized bed boiler can be described by the following equations:

\[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]

\[ \text{CaO} + \text{SO}_2 \rightarrow \text{CaSO}_3 \]

\[ 2\text{CaSO}_3 + \text{O}_2 \rightarrow 2\text{CaSO}_4 \]

Because of its relatively low cost, the FBC technique has become widely used for reducing \( \text{SO}_2 \) emissions from electricity-generating plants. Existing coal fired power plants can be modified to FBC, and therefore present a simple option for bringing older plants into compliance with clean air legislation (Wang et al., 1994).

**2.1.4. Flue-gas-desulphurization (FGD) ash**- It is the residue of alkaline scrubbing of sulphur oxides from flue gases of coal-fired power stations. A range of amendments including lime and ammonia are used to trap sulphur oxides, resulting in a range of FGD products. For example, FGD gypsum is obtained in the desulphurization of flue gases with lime or limestone suspension. Similarly, ammonia FGD is produced by reacting ammonium hydroxide with \( \text{SO}_2 \) to form ammonium sulphite, which is oxidized to ammonium sulphate. Apart from over 95% \( \text{SO}_2 \) removal capacity, this technology can also reduce the emission of other acid gases like sulphur trioxide and hydrogen chloride (Srivastava, 2000). The chemistry of the production of \((\text{NH}_4)_2\text{SO}_4\) from boiler flue gas is very similar to the chemistry of wet limestone FGD. \( \text{SO}_2 \) from the flue gas is absorbed in the spray tower by water according to the equation:

\[ \text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3 \]

The \( \text{H}_2\text{SO}_3 \) is then reacted in a reaction tank with ammonia to form \((\text{NH}_4)_2\text{SO}_3\) and \(\text{NH}_4\text{HSO}_3\):
\[ \text{H}_2\text{SO}_3 + 2\text{NH}_3 (\text{NH}_4)_2\text{SO}_3 \]

\[ \text{H}_2\text{SO}_3 + (\text{NH}_4)_2\text{SO}_3 2\text{NH}_4\text{HSO}_3 \]

(\text{NH}_4)_2\text{SO}_3 and NH\text{H}_4\text{HSO}_3 are also oxidized in the absorber (forced oxidation) to form (\text{NH}_4)_2\text{SO}_4 and NH\text{H}_4\text{HSO}_4. The NH\text{H}_4\text{HSO}_4 is neutralized in the presence of ammonia and water to form (\text{NH}_4)_2\text{SO}_4.

2.2. Characteristics of Fly ash

2.2.1. Chemical properties of fly-ash

Fly-ash is a complex heterogeneous material consisting of both amorphous and crystalline phases (El-Mogazi et al., 1988; Mattigod et al., 1990). It is generally considered a ferro-alumino silicate mineral with Al, Si, Fe, Ca, K and Na as the predominant minerals (Adriano et al., 1980).

Huge amounts of fly-ash released into the atmosphere are very fine particles, are generally spherical in shape and range in size from 0.5 µm to 100 µm, a low to medium bulk density, a high surface area and very light texture (Salter et al., 1971), and have increased concentrations of macro- and micronutrients (Elseewi et al., 1980). The concentration of various elements also varies according to particle size (Davidson et al., 1974; Page et al., 1979; Khan et al., 1996). Various elements that constitute fly-ash are Si, Ca, Mg, Na, K, Cd, Pb, Co, Cu, Fe, Mn, Mo, Ni, Zn, B, F, Ca and Al. This means that fly-ash contains most elements required for plant growth and metabolism, with the exception of nitrogen and available phosphorus, as well as most toxic non-essential elements for plants (Plank and Martens, 1973, 1974; El-Mogazi et al., 1988; Singh and Yunus, 2000).

<table>
<thead>
<tr>
<th>Properties</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (Alkaline)</td>
<td>8.2–12.8</td>
</tr>
<tr>
<td>EC (mmohs/cm)</td>
<td>8.60–8.70</td>
</tr>
<tr>
<td>CEC (mEq/100g)</td>
<td>0.52–1.28</td>
</tr>
<tr>
<td>Organic Carbon (%)</td>
<td>0.53–0.85</td>
</tr>
<tr>
<td>Total Nitrogen (%)</td>
<td>0.0–0.024</td>
</tr>
<tr>
<td>Total Phosphorus (%)</td>
<td>0.018–0.02</td>
</tr>
<tr>
<td><strong>Trace elements (µg/g)</strong></td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>20–153.5</td>
</tr>
<tr>
<td>Fe</td>
<td>53–4150</td>
</tr>
<tr>
<td>Ni</td>
<td>13–296.2</td>
</tr>
<tr>
<td>Mn</td>
<td>12.1–353.1</td>
</tr>
<tr>
<td>Cu</td>
<td>24.0–170</td>
</tr>
<tr>
<td>Cd</td>
<td>42.3–52.4</td>
</tr>
<tr>
<td>Pb</td>
<td>40.1–115.2</td>
</tr>
<tr>
<td>Mo</td>
<td>33.4–47.7</td>
</tr>
<tr>
<td>Cr</td>
<td>23.4–152</td>
</tr>
<tr>
<td>Na</td>
<td>15–98</td>
</tr>
<tr>
<td><strong>Major elements (µg/g)</strong></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>338–177,100</td>
</tr>
<tr>
<td>Mg</td>
<td>116–60,800</td>
</tr>
<tr>
<td>K</td>
<td>7,360–22,400</td>
</tr>
<tr>
<td>B</td>
<td>143–290</td>
</tr>
<tr>
<td>Al</td>
<td>4,615–24,200</td>
</tr>
</tbody>
</table>
2.2.2. Physical Properties of fly ash

The Fly ash particles are generally grey in colour and some of the pond ash is blackish grey, which are devoid of unburnt carbon. But when fly ash is mixed with bottom ash, overall carbon contents in the fly ash conglomerate and varies between ranges 3 and 5 percent. pH of fly ash varies from acidic to alkaline with electrical conductivity as high as 1 µS/m.

Table-2.2. Physical Characteristics of fly ash. (Source: Asokan (2003), Asokan (2000) and Sridharan et al. (1996).)

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Parameters</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Colour</td>
<td>Greyish</td>
</tr>
<tr>
<td>2.</td>
<td>Bulk Density (Kg/m³)</td>
<td>960-1500</td>
</tr>
<tr>
<td>3.</td>
<td>Porosity (%)</td>
<td>30-55</td>
</tr>
<tr>
<td>4.</td>
<td>Water Holding Capacity (%)</td>
<td>35-55</td>
</tr>
<tr>
<td>5.</td>
<td>Sand (%)</td>
<td>60-80</td>
</tr>
<tr>
<td>6.</td>
<td>Silt (%)</td>
<td>10-35</td>
</tr>
<tr>
<td>7.</td>
<td>Clay (%)</td>
<td>0.5-15</td>
</tr>
<tr>
<td>8.</td>
<td>Specific Surface Area (m²/kg)</td>
<td>0.1038-2.4076</td>
</tr>
<tr>
<td>9.</td>
<td>pH</td>
<td>3.5-12.5</td>
</tr>
<tr>
<td>10.</td>
<td>Electrical Conductivity (dS/m)</td>
<td>0.075-1.0</td>
</tr>
</tbody>
</table>

Physical properties like bulk density, texture, porosity and water holding capacity, etc., play an important role as far as the utilization is concerned whether in engineering applications or in agriculture purpose (Adriano et al., 1980; Asokan, 2003; Ferraiolo et al., 1990; Schure et al., 1985; Sridharan et al., 1996). Fly ash constitutes an assemblage of particles of wide variety of shapes and sizes, ranging from coarse sand to clays.
As per the United States Department of Agriculture standards, ~55% of Indian dry fly ash collected from ESP falls within the silt and clay sized particles and the rest is sand sized particles (Asokan et al., 1999). Figure 2.1 shows the particle size distribution and textural classification of Fly ash. The study carried out by Wigley and Williamson (1998), indicates that medium size of fly ash particle diameter is 20 µm and the maximum fly ash particles are usually in the range of 150–200µm.

![Particle size distribution of fly ash](source: Asokan, 2000 and Asokan 2003)

**Figure-2.1. Particle size distribution of fly ash**

The particles size distribution and texture of the Fly ash varied distinctly based on the source, topography of disposal site and location from where the ash is collected, and which was confirmed by several authors (Asokan, 2000; Rajasekhar, 1995; Sivapullaiah et al., 1998; Skarzynska et al., 1989).
The size distribution and surface area of a particular ash are important because they tend to influence the texture, sorption capacity, physico-chemical and engineering properties for different applications. According to Davison et al (1974) the concentration of the elements, Pb, Sb, Cd, Se, As, Ni, Cr, and Zn increased with decreasing particle size. The concentration of the elements Fe, Mn, V, Si, Mg, C, Be, and Al was found to increase with decreased particle size only for particles with a diameter less the 11 µm. These elements exhibited no size dependence for larger particles. The concentrations of Bi, Sn, Cu, Ti, Ca and K showed no dependence on particle size.

2.2.3. Microstructure of Fly ash

Several morphological classes of Fly ash particles observed by scanning electron microscopy showed that most of the Fly ash particles were regular in shape and size. And some of them were spherical, hollow shaped and cenospheres in nature (Asokan, 2003; Fisher et al., 1978; Kolay and Singh, 2001; Murarka et al., 1993). Microstructure of Fly ash may influence the binding properties, sorption characteristics of the final products or process. The morphology, physico-chemical characteristic of Fly ash significantly contribute even to improve the long-term properties of high performance concrete with 25–50% Fly ash application (Peter and Gopalakrishnan, 2004). It may also be seen in the micrograph where some of the cenospheres smaller size particles were adhered on bigger size particles. Further the cenospheres present in Fly ash helps as aggregate in developing lightweight concrete and other lightweight sound absorbing structural materials (Blanco et al., 2000; Tiwari et al., 2004).
Figure 2.2 Microstructure of Fly ash showing spherical, hollow shaped and cenospheres in nature.

2.2.4. Radio-active property of fly ash

The radioactivity level of Indian Fly ash and pond ash is almost similar to that of normal soil (Saxena and Asokan, 2001). But the radioactive level in lignite Fly ash is found less than that of bituminous and sub-bituminous coal ash (Vijayan and Behera, 1999). The measured level of these radionuclides in Indian Fly ash is below the limits specified from
environmental point of view. The upper limit for naturally occurring radionuclides such as $^{232}$Th (parent radionuclide of $^{228}$Ac), $^{226}$Ra and $^{40}$K are 259 bq/kg, 370 bq/kg and 925 bq/kg, respectively (Moghissis et al., 1978). Also the radioactivity concentration of Indian Fly ash is similar to the concentration reported for the Fly ash of United States and England and less than the corresponding level in the Fly ash of Poland, Denmark and Australia (UNSCEAR, 1982; Vijayan and Behera, 1999).

India has been stamped as a second largest emitter of Hg to the atmosphere and the largest amount stems from thermal power plants and heat producing units (Pacyna and Pacyna, 2001). Recently, problems of trace metals including lead (Pb), cadmium (Cd), mercury (Hg) and metalloid arsenic (As) have received much attention in the Indian subcontinent. In India many people have moved away from their homes due to health problems caused by coal burning and spreading of the fly ash. The issue of Hg has raised concern from chlor–alkali factories, thermal power plants and Hg wastes such as broken thermometers and instruments in the Indian subcontinent (Sharma, 2003).

2.3. Contamination of soil, water and air due to fly ash

Migration of contaminants from waste disposal sites to surrounding ecosystems is a complex process. Soil and water contamination around ash disposal site (Gulec et al., 2001) has recently been the subject of much research world over. Trace elements present on the surface of ash particles are readily leached (Shi and Sengupta, 1995; Fytianos et al., 1998) and tend to contaminate the groundwater (Theis et al., 1978; Carlson and Adriano, 1993). Toxicity of surrounding ecosystem results due to increase in metal concentrations beyond their threshold values. Groundwater pollution due to landfills has been studied by Christensen et al. (1994), Al-Muzaini et al. (1995), Ritterling and
Stansbury (1998), Jensen et al. (1999), Fatta et al. (1999), and Vadillo et al. (1999). Backman et al. (1998) have used groundwater contamination index for mapping the degree of contamination.

*Figure-2.3. Ground and surface water contamination*
2.3.1 Effect of fly-ash on soil properties

The effect of the incorporation of fly-ash into soil has been extensively investigated (Plank and Martins, 1973, 1974; Adriano et al. 1978, 1980; Elseewi and Page, 1984). The impact of fly-ash on soil largely depends upon the properties of the original coal and the soil examined. Fly-ash added to soil significantly increases the electrical conductivity of the soil mixture by increasing the levels of soluble major and minor inorganic constituents (Adriano et al., 1980; El-Mogazi et al., 1988; Eary et al., 1990). The initial increase in soil pH after alkaline fly-ash amendment is explained by the rapid release of Ca, Na, Al and OH ions from fly-ash (Hodgson et al., 1982; Wong and Wong, 1990). Excessive ‘Fe’ and ‘Al’ convert soluble Phosphate to insoluble Phosphate compounds, which are not readily available to plants. Fly-ash itself is not effective in retaining water, but it significantly increases water holding capacity of the soil mixture (Chang et al., 1977). Hydraulic conductivity of soils can be improved by the application of limited amounts of fly-ash, but it deteriorates rapidly when fly-ash input exceeds 20% (v/v) in calcareous soils and 10% in acidic soils. Fly-ash is an inorganic substrate that is rich in electrolytes and does not contain significant organic matter; therefore, its addition to soil results in increased hydraulic activity limited at lower application doses. The impedance of water flow is related to the podzolonic reaction of fly-ash, which reacts with water to cement soil particles under wet conditions (Adriano et al., 1980). Fly-ash also reduces the modules of rupture (cohesiveness of soil particles) in all soils tested (Adriano et al., 1980). Further details for fly-ash properties and its impact on soil mixtures have been described in previous reviews (Adriano et al., 1980; Carlson and Adriano, 1993). Field research in recent years has investigated the application of fly-ash with other solid wastes
(e.g. sewage sludge) to soils to serve as both a means of disposal and as a medium for plant growth. Organic amendments improve soil conditions by increasing the cation-exchange capacity and organic matter content of the soil, thereby resulting in increased immobilization of toxic elements, higher fertility and enhanced microbial activity. Certain inhibitory effects to soil microbes by toxic components of fly-ash may, furthermore, be attenuated by the application of organic materials (Chaney and Giordano, 1977). However, foliar application (2 and 4 gm per day) increased plant height, metabolic rate and photosynthetic pigment content in Zea mays and Glycine max. The highest foliar application at 8 gm per day caused reduced dry matter and pigment content. Ultimate analysis of G. max and Z. mays revealed that control plants were deficient in boron (Mishra and Shukla, 1986). The increased growth response and dry matter production of the two crops were attributed to the increased availability of boron. Mishra and Shukla (1986) and Rohrman (1971) studies that fly-ash consists of more than 10% water soluble components and there are reports of increased boron availability in fly-ash-amended soil (Martens, 1971). Boron from fly-ash was shown to be equally available to alfalfa as B from Na₂B₄O₇·10H₂O. This toxicity was caused by excessive boron uptake and the excessive alkalinity was caused by excessive soluble salts (Mishra and Shukla, 1986). Porosity is the air space between soil particles, which is usually occupied by water when available. So, the increase in water holding capacity is due to greater space between the soil particles. Electrical conductivity is positively correlated with pH and reflects the total concentration of soluble cations and anions (Elseewi et al., 1978) and it is quantitatively related to the concentration of salts. Normal values of electrical conductivity for vegetable crops range between 3 and 4 mmhos/cm, and higher values have adverse
effects on crop production (Hodgson and Holliday, 1966). The addition of appropriate quantities of fly-ash can also alter the soil texture. Fly-ash addition at 70 t/ha has been reported to alter the texture of sandy and clayey soil to loamy soil (Fail and Wochock, 1977). The grain size distribution, and especially the silt size range of fly-ash, affects the bulk density of soil. Chang et al. (1977) observed that among five soil types Reyes silty clay exhibited an increase in bulk density from 0.89 to 1.01, when the corresponding rates of fly-ash amendment increased from 0 (soil only) to 100% (fly-ash only). But in soils with bulk densities that varied between 1.25 and 1.60, a marked decrease in bulk density was observed with the addition of fly-ash. Page et al. (1979) reported that the amendment of fly-ash to a variety of agricultural soils tends to decrease bulk density. The optimum bulk density in turn improves soil porosity, root penetration and the moisture retention capacity of the soil.

The activity of certain metals may also be increased with an increase in pH. For example, aluminium (Al) is relatively insoluble as Al(OH)₃ at neutral pH, but it exists predominantly as highly soluble and toxic aluminate anions above a soil pH of 8.0. As soluble aluminium can exist in various ionic forms in aqueous solution, various researchers have tried to explain the mechanisms of Al phytotoxicity, but have been limited by a lack of understanding of Al speciation. At mildly acidic or neutral soil pH values, Al is primarily in the form of soluble alumino silicate/oxides; as the pH become more acidic a phytotoxic form of Al is released into the soil. Thus, Al toxicity is the major growth-limiting factor to crop cultivation on acid soils (Foy, 1984; 1988). Recent evidence shows that Al can readily enter the symplasm of root cells (Lazof et al., 1994). Al, when in a symplasmic solution of pH above 7, contains a mixture of various
macromolecules and constitutes a crucial aspect of Al toxicity. It has been inferred that Al toxicity is better correlated with either some or all the monomeric hydroxy Al species, or is a combination of Al$^{3+}$ and certain other monomeric hydroxy-Al species, instead of Al$^{3+}$ alone (Balmey et al., 1983; Alva et al., 1986; Kochian, 1995). It has further been suggested that for dicots either Al(OH)$^{2+}$ or Al(OH)$^{3+}$ is the phytotoxic species and Al$^{3+}$ is much less toxic (Alva et al., 1986; Kochian, 1995).

This situation is prevalent in fly-ash that has higher pH values. Al$^{3+}$ is the toxic species for monocots, e.g. in wheat roots, when Al$^{3+}$ activities were increased, the activities of the hydroxy-Al species were decreased (Kinraide and Parker, 1987; Kiniraide, 1991; Kochian, 1995). In India, most of the fly-ash produced is alkaline in nature. Hence, an application of this to agricultural soil increases soil pH. This property of fly-ash can be exploited to neutralise acidic soils (Elseewi et al., 1978; Phung et al., 1978). Jastrow et al. (1979) reported that while the addition of fly-ash improves soil pH, it also concurrently adds essential plant nutrients. Page et al. (1979) observed that experiments with calcareous and acidic soil revealed that fly-ash addition elevated the pH of the former from 8.0 to 10.8 and of the latter from 5.4 to 9.9. It must be noted here that the use of excessive quantities of fly-ash to alter pH can cause an increase in soil salinity, especially with unweathered fly-ash (Sharma et al., 1997).

2.3.2 Effects of fly-ash on plant growth and vegetation

Fly-ash particles are very fine in nature and thus tend to remain airborne for a long period. Fly-ash dust, under certain conditions of humidity, sticks to the leaves and promotes chemical as well as physical damages and small necrotic dark brown spots appear on the leaves of many vegetables such as green beans, turnip, cabbage and tomato.
(Singh and Yunus, 2000). At lower fly-ash deposition rates fly-ash particles accumulate on the guard cell surface and stimulate the mechanism regulating stomatal opening and closure, and prevent them from closing (Fluckiger et al., 1979; Krajickova and Majstrick, 1984), thereby restricting increased transpiration rates. Foliar application of higher fly-ash deposition rates (8 gm per day) resulted in decreased transpiration rates due to the barrier created by a thicker layer, and thus reduced vapour loss from the leaves (Mishra and Shukla, 1986). Thick coating of fly-ash interferes with the light required for photosynthesis and thus reduces the photosynthetic rate. Leaves laden with fly-ash particles absorb heat more effectively and, consequently, the increased leaf temperature results in increased transpiration rates. Airborne fly ash particles may affect many functions of plant shoots as well as those of other living organisms. Changes in soil properties caused by fly-ash may directly or indirectly change microbial activity and the root growth of plants. Fly-ash increases water-holding capacity of soil mixtures, but this capacity does not appear to significantly increase the available water to plants (Chang et al., 1977).

Field and greenhouse studies suggest that many chemical constituents of fly-ash benefit plant growth due to micronutrients and can improve the agronomic properties of the soils (Chang et al., 1977). A lower application of fly-ash (5–10%) in soils accelerates seed germination as well as seedling growth, although higher application (20–30%) either delays or drastically inhibits plant growth, development and other specific parameters (Singh et al., 1997). When Beta vulgaris roots were grown in fly-ash-amended soil it was found that low fly-ash application of up to 2% (kg/m² plot) was stimulatory for sugar production whereas higher doses (4 and 8%) were inhibitory (Singh et al., 1994; Singh
and Yunus, 2000;). Deleterious effects of larger applications of fly-ash on plants are primarily attributed to a shift in the chemical equilibrium of the soil (Singh and Yunus, 2000). Both the high alkaline pH and the excess levels of soluble elements released from fly-ash induce hazardous effects in plant roots and the rhizosphere. Increased soil pH results in a loss of applied and indigenous soil N. The high pH in fly-ash is hazardous to the major microbes that conduct N fixation and other important functions for plant growth. Fly-ash delays nodulation in plants, resulting in fewer nodules (Martensson and Witter, 1990). Evidence has been presented for the toxic effects of specific fly-ash constituents in plants. Especially, As, Se, Mo, V, Al, Cd and B are noticed to be highly hazardous to plants if accumulated in plant tissues. These elements are readily available to plants and accumulate in the tissues (Townsend and Hodgson, 1973; Hodgson and Buckley, 1975; Adriano et al., 1980; El-Mogazi et al., 1988; Inouhe et al., 1994; Singh et al., 1997; Rai et al., 2000). Fly-ash has ppm level concentrations of heavy metals when applied to soil. These trace elements may be taken up by plants, which may slowly enter into the food chain. The data on trace metal uptake and accumulation are limited. Boron in fly-ash is readily available to plants and B has been considered to be a limiting factor in unweathered fly-ash utilization (Townsend and Gillham, 1975; Elseewi et al., 1978). The highest concentration of some metals, such as Cu, Fe, Zn and Ni, was recorded in plants grown in fly-ash amended with press mud, followed by fly-ash plus cow manure, raw fly-ash and fly-ash plus garden soil, respectively. The greater availability of metals has been correlated with a lowering of pH of fly-ash after the addition of press mud (Tripathi et al., 2000). Plants have various intracellular sites and/or metabolisms that are very sensitive to metal ions and, hence, may readily suffer from the additive and
synergistic effects of different toxic metals (Woolhouse, 1983) present in fly-ash. In turn, plants that have a detoxification or immobilizing mechanism against specific heavy metals can be candidate members for reclamation on fly-ash soils. Here, roots are the first organ that comes in immediate contact with the toxic metals in soils and most of the toxic metals can be deposited in the root tissues. Metal deposition in the root may restrict movement of the toxic metals to the leaves and other shoot organs (Mishra and Shukla, 1986; Inouhe et al., 1994). Therefore, the different tolerance characteristics of roots can be an important factor limiting the overall plant growth responses to the fly-ash constituents. K deficiency in plants grown on lagoon ash was found to be mainly caused by the high Ca content of the ash. An increase in available Ca and Mg in the absence of an increase in available K may antagonize plant K uptake, and eventually cause K deficiency (Plank and Martens, 1973). The impact of fly-ash on plants has been also investigated at a larger scale in selected fly-ash landfills or sites with tree vegetation (Singh and Yunus, 2000). Scanlon and Duggan (1979) planted eight species of trees and shrubs in a dewatered fly-ash landfill in Tennessee. They found that survival varied among the species (12 to 84%) and the foliar tissues had elevated levels of B, Ni and Se, and, in some cases, As, Cd, Cu and Zn. In South Carolina, four tree species were planted on an abounded fly-ash basin that showed minimal natural re-vegetation (McMinn et al., 1982). These field experiments showed a high survival of plants on the alkaline fly-ash site than on the control site. They also reported elevated levels of some trace elements, including B, Cr, Co, Cu and V, but reduced levels of Mo and Mn in the trees grown on the fly-ash site. Carlson and Adriano (1991) also reported elevated trace element concentrations in sweet gum and sycamore (Platanus occidentalis L.) grown on two
abounded coal fly-ash basins. Although there are some discrepancies in metal accumulation by plants in field conditions, it is evident that fly-ash has a dual effect in various plants, i.e. promotion and inhibition of growth in a dose-dependent manner. The nutrients from fly-ash have been reported previously to be beneficial to plants through soil application or foliar dusting (Mishra and Shukla, 1986). Because fly-ash lacks nitrogen, its application, especially at higher concentrations, results in severe deficiency of nitrogen in soil as well as in plant tissue, which is an important factor responsible for the suppressed growth and yield. Aluminium and manganese toxicity in fly-ash exhibits different degrees of responses from the various indicator plants employed. Three types of plant responses to excess aluminium in fly-ash may be distinguished by complete tolerance (Atriplex), partial tolerance with no phosphate problems (spinach) and great sensitivity (barley). Aluminium-induced root abnormalities were not evident with ash-barley, but were due no doubt to the high ash calcium. Acaciasp. And Leucaena leucocephala have been demonstrated to have high tolerance and survival in arid, infertile and metal-contaminated areas (Barnet et al., 1985; Mulhern et al., 1989; Muslin, 1993). In addition, legume plants and symbiotic N-fixing bacteria can improve the nitrogen (N) content of infertile soils (Sanginga et al., 1994). Acacia auriculiformis and Leucaena leucocephala are well adapted to the climate of southern China; thus, they were selected as the study species in the revegetation trial of Zhang et al. (1998). Leguminous vegetation, such as Cassia siamea and Pisum sativum, were found to accumulate Zn, Cu, Ni and Fe at various doses of fly-ash application (25, 50, 75 and 100% fly-ash in soil; Tripathi et al., 2000). Fly ash has been utilized to boost the productivity of a few agricultural crops and leguminous trees (Kumar et al., 2001; Rai et al., 2002; Tripathi et
al., 2002). *Cassia siamea* has been found to have antioxidants and a metal detoxification potential when grown on fly-ash and fly-ash amended with press mud (Kumar et al. 2002).

### 2.3.3. Contamination of ground and surface water

Water pollution stands for the contamination of water due to some external materials. Water may be polluted either from natural sources or human sources. Transport of pollutants through ground water flow is very complex phenomenon. A range of physical, chemical and biological processes can influence the tracer drift by the ground water flow. Wastewater discharge impacts on the receiving water can be grouped into chemical, biological, physical, hygienic, esthetic, hydraulic and hydrologic impacts. They can be further classified in terms of duration as acute, delayed or accumulating. Groundwater and surface water are fundamentally interconnected. It is often difficult to separate the two because they feed each other. This is why one can contaminate the other. Water is an ideal solvent, some products placed on or in the soil will eventually end up in the ground water (Dimter and Rukavina, 2007).

In India, industrial utilization of fly ash is about 38% of the total produced (Alam and Akhtar, 2011). The rest of the fly ash is disposed of either by dry methods of disposal in landfills or by wet methods of disposal where the ash is mixed with water and removed as slurry for settlement in ponds. The supernatants are discharged into a receiving system and the final effluents discharged into a natural aquatic drainage system like a river. Both the dry and wet disposal of fly ash can result in metal contamination of surface and groundwater.
Near the ash ponds, water quality is changed owing to the leaching of soluble ions present in fly ash. Addition of fly ash to the native soil leads to an increase in the availability of nutrient ions like Cu, Ni, Zn, Fe, P, K and Na and enhanced growth of plants. The leaching potential of these heavy metals from an open system (fly ash pond) is expected to be greater due to diurnal and seasonal variation in temperature, moisture content and other parameters. Leaching, movement of water through materials containing soluble components significantly influences the surrounding soil, groundwater and surface water. Variable chemical composition of fly ash can contain elements that will infiltrate ground water or surface water by leaching and ultimately can pose significant danger to the flora and fauna. Influence on water quality has the presence of heavy metals (As, Cd, Cu, Cr, Hg, Pb, Zn etc.)
A study of heavy metals in groundwater near a coal ash disposal site in Orissa, India showed that Zn, Cu and Pb were found in high concentration in tube well water located in the vicinity of an ash pond while Cu, Mn, Pb and Zn were the major contaminants in groundwater.

Most of the elements (As, Ca, Mg, Mn, Na, S and Zn) showed maximum concentrations in the leachate at low liquid solid ratio (L/S) of 4 and 8 and then decreased at higher L/S, indicating that with successive volumes of infiltrations of rainwater through the ash pile, the concentrations of these elements in the leachate would reduce significantly. It was also found that some elements, which were present in bulk fly ash, were insignificant in the leachates (Cu and Pb), while some others (Cd, Co, Cr and Ni) did not leach at all regardless of L/S ratio.

Due to leaching characteristics of fly ash, the heavy metals along with other constituents gradually and slowly get leached from the ash and percolate to nearby ground water. This raises the threat of percolation of hazardous elements contained in the fly ash to ground water and sub soil degradation from the ash ponds. The potential of leaching of these metals not only depends on the total metal contents of fly ash but also influenced by the crystal structure of fly ash. The release of metals in the leachate may be from the outer surface of fly ash particle or from inner matrix of the particle.

Earlier result shows that the fly ash is rich with calcium and has low sulphur contents. This composition of the ash results in very basic solution. When fly ash interact with water the pH increases to higher than 9.0 due to dissolution of calcium oxides which is contained in the outer surface of the ash particles because of its high volatility. The density of ash also influences the leaching efficiency due to water movement through it.
2.3.4. Impacts of fly ash on animals

Impacts on animals inhabiting locations contaminated with coal fly ash have been demonstrated in many studies. For example, adult southern toads (*Bufo terrestris*), freshwater grass shrimp (*Palaemonetes paludosus*) and fish (*Erimyzon sucetta*) have been shown to accumulate trace elements from coal ash polluted areas, including arsenic and cadmium (Hopkins *et al.*, 1999). Larval southern toads (*Bufo terrestris*) and larval bullfrogs (*Rana catesbeiana*) inhabiting similar sites have been shown to suffer elevated incidences of survival-threatening physiological impacts (Hopkins *et al.*, 2000). Such effects are believed to result from the complex mixtures of pollutants in coal ash. Amongst these are elements such as selenium, chromium, cadmium and copper, known to have the potential to be teratogenic to such species.

The ability of toxic elements to leach from coal fly ash has serious implications where such ash are added to agricultural land as soil stabilizers. Plants grown on soils amended with coal fly ash have been demonstrated to absorb a range of potentially toxic elements (El-Mogazi *et al.*, 1988). Furthermore, grasses and legumes grown on soil capped coal fly ash landfill sites can become enriched with potentially toxic elements (Weinstein *et al.*, 1989).

2.4. Classification of Indian Fly ash

Indian coals are classified according to their useful heat values and assigned grade from A to G in decreasing order of useful heat values. The grade of coal used at the IPS and RPH power stations (same source for both power stations) has been reduced over the years (personal communication). Although A, B or C grade coals were used in the past (useful heat values, uhv, of these coals being 25.94 MJkg\(^{-1}\) for grade A, 23.43–25.94
MJkg\(^{-1}\) for grade B, 20.67–23.43 MJkg\(^{-1}\) for grade C), in recent years only D, E and mainly F grade coals have been used (uhv of D grade coals being 17.57–20.67MJkg\(^{-1}\), E grade coals being 15.06–17.57MJkg\(^{-1}\) and F grade coals being 10.04–17.57 MJkg\(^{-1}\)). Ash content of the coal used ranges between 38-40% and even goes up as high as 47% (Mehra et al., 1998). There are reports of instances of major dust pollution around these power stations from fly ash dispersal (Padmanabhamurty and Gupta, 1977; Fulekar, 1993; Mehra et al. 1998).

Indian fly ash are derived from high ash (mineral matter), and low calorific value coals. Moreover, enrichment associated with combustion may concentrate elements by factors of four to ten times (Fernandez-Turiel et al., 1994). Ash may contain As, B, Be, Ca, Cd, Cr, Fe, Hg, Mg, Mo, Na, Ni, Pb, Ra, Se, Th, U, V, Zn, etc. either on the surfaces of ash particles or in the aluminosilicate matrix phase or in both, as a consequence of volatilization and condensation during combustion (Henry and Knapp, 1980; Hansen et al., 1984; Smith, 1987). Elements having their surface association may release more rapidly than those contained in glass and crystalline fraction (Ramesh and Kozinski, 2001). Generally, glass phase and magnetic fractions in combustion residues contain most of the potentially toxic elements (Zevenbergen et al., 1994; Kukier et al., 2003). Elements like Pb, Cd, Cr, As and Hg may cause detrimental effects on human health and aquatic life (Lal C Ram et. al., 2007). Fly ash in contact with water may experience solid phase dissolution, with changes in pH and release of toxic trace metals (Fulekar, 1993). The principal processes affecting the leaching process are dissolution of primary solids, precipitation of secondary solids, as well as sorption and hydrolysis reactions etc. (Jankowski et al., 2006). Free lime in the fly ash may have higher reactivity, leading to
several problems, including leaching of trace metals to the ground water and cations and anions in ash may increase the hardness, salinity, alkalinity and proportion of dissolved solids in soils (Fulekar and Dave, 1989).

2.5. Leaching Impact and fly ash problems

The growth of large industries in Delhi is limited due to introduction of planning restrictions, small scale industries have expanded rapidly with a more than 500% increase in industrial units from 18,500 in 1961 to 93,000 in 1993 (CPCB, 1993–1994). Indraprastha Power Station (IPS), Rajghat Power House (RPH) and Badarpur Thermal Power Station (BTPS), owned by IPGCL and NTPC respectively are coal fired power stations situated on Ring Road and Badarpur in Delhi on the bank of River Yamuna. North of these power stations is the Wazirpur area which is home to numerous small scale metal manufacturing and processing industries which may add to the metal load of soils in their vicinity.

Leaching tests have been commonly used to predict environmental impact associated with ash disposal, which is produced from coal based power generation. Comparison of groundwater contamination in the vicinity of a thermal power plant in Turkey with leaching tests revealed that certain leaching tests can be used to predict contamination from toxic elements in ash (Baba and Kaya, 2004).

Presently ash pond lining is not being followed in these ash ponds. Therefore, the possibility of leaching of the heavy metals increases. Since, soil below the impoundments is always saturated and under considerable hydraulic head, the inefficiently lined ponds provide a great opportunity for the groundwater contaminants to seep in. Therefore, seepage from ash ponds may be more compared to leaching from landfills and ash
mounds (Theis et al., 1978). In addition to this, discharge of rain water and run off from the ash mound areas into surface water bodies can also be a source of water pollution. Therefore, it is necessary to incorporate ash pond lining while designing ash ponds. Planting of saplings having tolerance to warm slurry water and heavy metals is considered to be the most ideal mitigation measure, since the biomass can also adsorb toxic metals as nutrients and can also provide obstruction for windblown particulates (Sahu, 1996).

The rate and quantity of such leaching is dependent on a number of factors, which include the fly ash source and leaching time (Egeman & Coskun, 1996). In general, higher rates and quantities of leaching occur under more acidic conditions (low pH). While most fly ash and their leachates are alkaline (higher pH), fly ash leachates can vary from acidic (pH=4.2) to alkaline (pH=12.4).

Studies designed to approximate field conditions have shown that those metals generally found to leach to the greatest extent were cadmium, chromium and lead (Fytianos et al., 1998). The use of pure water has been shown to result in the leaching of appreciable fractions of the arsenic, chromium, cobalt, copper, nickel, lead and zinc present in coal fly ash (Llorens et al., 2001). Certain trace elements present in fly ash, including chromium, lead and zinc, can also be leached by seawater (Kress, 1993).

### 2.6. Leaching methods applied to the characterization of coal fly ash.

There are several leaching methods available for predicting the leaching potential of contaminants through porous media. Some of them are conducted under natural weather conditions and the others are performed under controlled laboratory conditions. Though different agencies have their own specifications for conducting leaching tests, the basic
principles of the tests are the same. Tests performed under natural conditions may provide better representation of the field conditions but they are less reproducible because the weather conditions cannot be controlled.

Information on analytical methods related to the release of heavy metals from fly ash in aqueous environment is very limited. Most of the papers related to heavy metals release, predict the long term leaching behavior of metals simply by extrapolating available test data. Various procedures have been employed to carry out the analysis of the bottom and fly ash of the thermal power plants and to evaluate their effectiveness. Each method has a specific advantages and are applicable for certain data collection system. In order to evaluate such methods knowledge of the leaching behavior of the studied material is very important. One of the factors influencing the leaching behavior is the composition and mineralogy of the solids.

Leaching is the most likely path by which coal bottom ash constituents would become mobile and environmental contaminants. The quantity of elements that will be available for leaching in an aqueous media will depend on the fixation of these elements on the ash particles and pH of the ash-aqueous medium (Sivakumar and Datta, 1996). In addition to this, the other factors influencing leaching include ash source and leaching time. In general, under acidic conditions the rate and quantity of leaching is higher. Certain studies reveal that for most of the elements present in coal ash, a significant fraction, ranging from 8% in case of nickel to 17% in case of chromium, is able to leach.

Leaching is a method to remove soluble components from a solid matrix. A survey of the literature identified over 100 leaching methods. Given the plethora of methods, the
question often arises as to what is the most suitable method. The simplest answer is by describing leaching by a very simple equation:

\[
\text{material (leachee)} + \text{leachant} \rightarrow \text{leachate}.
\]

It can be assumed that the material to be leached is known, although its physical, chemical and mineralogical properties may affect the final result. The purpose or what you expect to find in the leachate will determine the selection of a leachant and also the conditions of the test.

Several common leaching methods are regulatory methods, mandated to characterize materials; others are approved by organizations for establishing compliance to particular specifications. Some methods are intended to imitate natural conditions or to obtain information about the nature of the extractable material within a particular solid. The methods vary in the mass and particle size of the sample, the type and volume of leachant solution(s), the leachant delivery method, and time. Most procedures are performed at ambient temperature, although a few decrease the time required to solubilize components by increasing the temperature. Although many were developed for application to municipal solid waste or industrial wastes, most leaching methods have been applied to a variety of materials, including coal utilization by-products.

There are a number of test methods which have been used to determine the release of contaminants from coal combustion residues, such as bottom ash, and fly ash. These methods yielded indicating a variety of results related to the coal composition, the combustion type and the adopted extraction process. For the purpose of this review these procedures are broadly classified into three basic types of leaching tests. These three types are (a) lysimeter tests, (b) column tests and (c) batch leaching tests.
2.6.1. Lysimeter Tests

Generally, Lysimeter tests are conducted in the field on large samples of fly ash as leaching experiments. In this process, the sample is subjected to natural weather conditions for a couple of years and leachate collected and analyzed. Lysimeter tests are done in a number of lysimeter cells. Each lysimeter cell has a fairly large surface area and contains a substantial quantity of the sample. The base of each lysimeter cell is lined to prevent the infiltration of leachate into the ground. A drainage system is used to collect leachate produced in the lysimeter cells. The leachate collects into pumping sumps which contain buffering tanks from where it is then pumped to storage tanks. The leachate samples can be analyzed periodically. The quantity of leachate produced and the precipitation received during the test period are also calculated from available data.

2.6.2. Column Tests

Column leaching tests are laboratory tests. In this type of testing, fly ash samples are packed into transparent plastic cylinders. Influent and effluent tanks are used for influx generation and effluent collection process respectively. To prevent clogging of the pipe system from the material that is washed away, filters are used at the inlet an outlet sides of the fly ash column. The direction of flow through the column may be upward or downward depending on the specific research objectives. For minimizing channeling effect, the upward flow mode is recommended. Constant flux through the material may be achieved by using constant flow rate pumps between the influx reservoir and column inlet. To simulate one dimensional flow situations the column leaching test is preferred.
2.6.3. Batch Leaching Tests

Batch leaching tests are also laboratory tests performed to determine leachability of materials. These tests consist of a series of extraction performed sequentially. In this test, known amount of material and volumes of influx fluid, expected to infiltrate for a given period of time, are placed in polyethylene bottles. The bottles are then rotated end-over-end for the same assumed leaching time period at a specified RPM. Once this process is complete, the leachate is removed from the bottle and filtered for further analysis. A new portion of influx fluid is added to the residue for a second extraction. The number of extraction performed depends on the requirements of the researcher. The amount of material to be taken for the test and RPM for rotating may vary according to the specifications established by different agencies. The American Society for Testing and Materials (ASTM) procedure uses reagent water as the leaching fluid, and the method does not require particle size reduction.

2.6.4. Summary of Test Methods

Fly ash is a heterogeneous material and hence concentration of contaminants produced from different leaching test methods varies significantly from one test procedure to another. However, among the most widely used methods, the batch leaching test (laboratory test) has been selected for the research. Since the objective of this study is to use a laboratory method for studying the leaching behavior of metals from ash, the batch leaching test was selected over other test methods as the test procedure which will best meet the objectives of this research.
2.7. Utilization of fly ash

Fly ash is utilized in cement and construction industry. However, the rate of production is greater than the consumption. The unused fly ash is disposed into the holding ponds, lagoons, landfills and slag heaps. Disposal of huge amounts of fly ash in landfills and surface impoundments or its re-use in construction materials is of environmental concern (Piekos and Paslawska, 1998). Fly ash is classified as a hazardous residue. Coal contains significant quantities of various trace elements and, during combustion of coal, trace elements are enriched as a result of carbon loss as carbon dioxide and the trace elements are associated with the surface of the ash particle due to evaporation and condensation. The characteristics of the coal used and the type of the installation employed in generating the solid combustion wastes (fly ash) have a direct influence on chemical and mineralogical composition of fly ash (Benito et. al., 2001).

The use of fly ash in plastic composites has shown promise (Jarvala and Jarvala, 1996; Verghese and Chaturvedi, 1996; Yildirim et al., 1996), as has application in metal composites, in particular aluminium (Rohatgi et al., 1995; Guo et al., 1996, 1997). Aluminium alloy fly ash composites made by stir casting exhibited similar or higher hardness and elastic modulii, and improved wear abrasive resistance and were considered potential materials for components like pulleys, oil pans, intake manifolds and valve covers (Guo and Rohatgi, 1997). Coatings made from nickel fly ash composites were found to possess better wear resistance than ‘plain’ nickel coating. The higher wear resistance of the composites was attributed to the excellent bonding between fly ash particles and the nickel (Ramesh and Iyer, 1991). Fly ash can be used to reduce the density of metal composites, with the cenospheres (hollow spherical particles) within the
ash providing added buoyancy, better insulation properties, reduced shrinkage and warp age values (Wandell, 1996).

Figure-2.5. Utilization of fly ash for various applications.

Fly ash filled unsaturated polyester resin has been cast into sheets and tensile strength, flexural strength and flexural modulus compared with calcium carbonate filled polyester resin (Saroja Devi et al., 1998). The fly ash filled polyester resin was found to have a better flexural modulus than the calcium carbonate filled polyester resin. Fly ash from 0–50% content has also been mixed with post consumer polyethylene terephthalate (PET) to produce a molded composite material (Yadong et al., 1998). The fly ash reduced the thermal decomposition of PET, expedited the melting and mixing characteristics and
reduced the shrinkage of material during the moulding process. The addition of fly ash also increased the compressive strength by 31–53% and water absorption was found to be negligible.

Adsorption of arsenic on fly ash was found to conform to Freundlich’s isotherm and the efficiency of adsorption was comparable to activated carbon (Sen and De, 1987). Arsenic was also successfully removed from samples of industrial wastewaters. Adsorption of cadmium and chromium from wastewater by adsorption onto fly ash was investigated to determine the effects of contact time, pH and temperature (Viraraghavan and Rao, 1995). An aqueous medium pH of 7–8 was found optimal for removal of cadmium and a pH of 2–3 for chromium. Batch adsorption experiments conducted at 5, 10 and 21°C showed that the adsorption capacity of fly ash decreased with increase in temperature. The maximum removal levels at 5°C of cadmium and chromium were 93 and 44%, respectively.

Fly ash effectively adsorbed mercury from wastewater when the contact time was 2 hour and the pH was 5–5.5 (Viraraghavan and Kapoor, 1992). When fly ash was treated with radionucleotide containing water, removal of cesium-137 was at a maximum at neutral pH, whereas strontium-90 adsorption increased with pH, especially above pH 8 (Resat et al., 1996). Tobermorites synthesized from oxides and from fly ash has also been shown as a resource in the separation, immobilization and disposal of radioactive species, such as Cs and Sr (Ma et al., 1995). The acid-base properties of fly ash were found to be suitable for the removal of heavy metals such as nickel, cadmium, chromium, lead, copper, mercury and zinc from industrial wastewaters (e.g. electroplating and battery manufacture). Fly ash being readily available and inexpensive was considered an
economic alternative to conventional adsorbents such as activated carbon and ion-exchange resins.

In stochastic approach transport of pollutants in porous medium is accidentally processes and variable for flow and transport are accidentally characteristic too. Flux liquid phase and transport everyone components is always three dimension process. Chemical and biological reaction that can change concentration contamination in ground water can be divided in six groups: (Sperac, 2003)

1. Processes of adsorption and desorption
2. Reaction at the sour base
3. Processes of melt and sedimentation
4. Oxidation and reduction
5. Ionization connection
6. Microbes cellular synthesis

2.8. Statement of the problems

Fly ash contains a large number of heavy metals such as Fe, Cu, Cr, Ni, Pb and Cd. During the coal combustion process, the heavy metals present in the parent coal tend to concentrate preferentially on the finest particles due to volatilization-condensation mechanism (Teixcira et al., 1992) and it is observed that the heavy metal concentration tend to increase with the decrease in the fly ash particle size (Sharma et al., 1989). Among the metals As, Cd, Cr, Se, Hg, Pb are toxic to human health, whereas B is toxic to plants. These trace metals are released readily in aqueous environment. Leaching can be described as the fluid extraction of a compound or element from a solid. It is an interactive process in which both leachant and solid variables can control the results. The
pH of the leachate, which is determined by the pH of the leachant and the alkalinity/acidity of the solid is generally recognized as a controlling factor. The leaching potential of heavy metals depends on the alkalinity or acidity condition of the aqueous environment. If a methodology could be developed to predict the potential of heavy metals to leach out of fly ash it can be beneficial in a number of ways. Such a methodology will help to evaluate the impact of fly ash on the environment. Similarly it can be used to determine the amount of different metals that can be recovered from fly ash leachate, provided appropriate procedures for metal extraction from fly ash leachate are available.

2.9. Objectives of the Study

The objectives of this research study are as follows:

i. Fly ash sampling from selected coal based thermal power plants and ground & surface water sampling including nearby villages of these thermal power plants in Delhi.

ii. Laboratory batch leaching tests on fly ash samples with periodic analysis of leachate to determine the maximum amount of contaminants that can be leached from fly ash.

iii. Estimation of solutes in the supernatant of a wet disposal system and measurement of the concentration versus time profile for solute extracted from fly ash.

iv. Study for the concentration of trace elements in ground and surface water samples in surrounding area of these thermal power plants and to examine the impact of fly ash on surface and ground water.
v. To assess compliance with regulatory criteria for the safe disposal of fly ash from thermal power plants.

2.10. Research Approach

This section presents a brief description of the general research approach used in this research study. Detailed accounts of various tasks completed in this research are presented in the subsequent chapters. As a first step in this research, an extensive literature survey was conducted to collect information on existing laboratory procedures which have been developed to study leaching behavior of metals in porous media. Among all the leaching methods reviewed, laboratory leaching test known as batch leaching test is adopted in this research. For a fly ash with given composition, the metal concentration in the leachate is controlled by influent pH and the influx velocity. Therefore, three combinations of leaching test were used in this study. The fresh fly ash samples were collected from the ESPs of thermal power plants. The leaching study was performed in extraction apparatus. The leachate collected periodically was filtered using 0.45 micron glass fiber filter, pH of effluents was measured and the leachate was analyzed for heavy metal concentrations. The fly ash material tested in this research belongs to "Class F" category. These fly ash samples were collected from the hopper bottom of Indraprastha Power Station, Rajghat Power House and Badarpur Thermal Power Station which is coal fired power stations located on Ring Road and Badarpur in Delhi on the bank of River Yamuna. The heavy metal concentrations in leachate of the fly ash samples were determined by an Atomic Absorption Spectrometer in the Advanced Instrumentation Laboratory, University School of Environment Management, Guru Gobind Singh Indraprastha University.