CHAPTER 1
Introduction

1.1 Background

Waste material is defined as a left-over part of a product/material which does not have any significant value for its proprietor and hence is discarded. The word waste generally reveals about the material which is of no use. However, most of the waste material can be utilized in a variety of different industrial processes and energy production through incineration, if the practice of their proper management is followed. Management of waste material is utmost necessary for the sustainable future of the society. It is practiced since the dawn of early civilization, but only 100 years before it comes as a topic of research and discussion. The waste material may be found in the form of a solid or fluid phase. The sources of waste material can be divided into institutional, residential, industrial (processing), industrial (non-processing), commercial, municipal, agricultural, and treatment plant wastes.

1.1.1 Waste management

Increase in the waste quantity along with the heterogeneity, is one of the significant issues in the management of solid waste. The arrival of non-regulatory waste and un-availability of technical quality data is adversely affecting the handling of such materials. There is a chief necessity of the society to take swift action to deal with inadequately managed waste materials. The urbanization of society leads to generation of considerable wastes per capita, in the form of industrial, commercial, residential and municipal wastes. The classification of these wastes is summarized in Table 1.1 (O'leary et al., 2002). According to the global estimate of the year 2016, 19.09 kg of waste is generated per capita per day (Kaza et al. 2018). Systematic management of the waste of all kinds with segregation, proper collection, hauling system, treatment and finally disposal is required not only in the developed high-income group countries but middle- and low-income group developing and least developed countries. Fig. 1.1 deals with the different processes, which are being followed in practice for solid waste management in the order of their preferences.

Table 1.1 Classification of solid waste

Source	**Location or process**	**Type of waste**
Institutional	Hospitals, schools, community centers	Plastics, wood, paper, cardboard, food waste, metals and glass waste, etc.
Residential	Nuclear family, joint family, low, middle or high-density place.	Plastics, wood, paper, cardboard, food waste, aluminum, other metals, and glass wastes, ashes, electronic wastes, white goods, oil, batteries, hazardous waste, textile waste, yarn, etc.
Industrial (processing)	Heavy manufacturing, chemical plants, construction, fabrication, refineries, power plants, etc.	Scrap materials, ashes, construction and demolition wastes, process wastes, non-industrial waste (including food waste), hazardous waste, etc.
Industrial (non-processing)	Heavy and light manufacturing, construction, chemical plants, fabrication, demolitions, power plant, etc.	Plastics, food wastes, glass, ashes, metal wastes, hazardous waste, paper, cardboard, wood, etc.
Commercial	Office buildings, hotels, restaurants, departmental stores, service stations, repair shops, etc.	Cardboard wood, plastics, paper, food wastes, metal wastes, hazardous wastes, glass, ashes, etc.
Municipal services	Parks, street cleaning, recreation facilities etc.	Special wastes, rubbish, street sweepings, debris, general wastes from parks and recreation facilities
Agricultural	Farms general wastes, row crops, post-processing wastes, etc.	Rubbish wastes, hazardous wastes, spoiled food wastes,
Treatment facilities	Industrial treatment, water, and wastewater treatment processes etc.	Sludges (majorly composed of treatment wastes and residual materials)

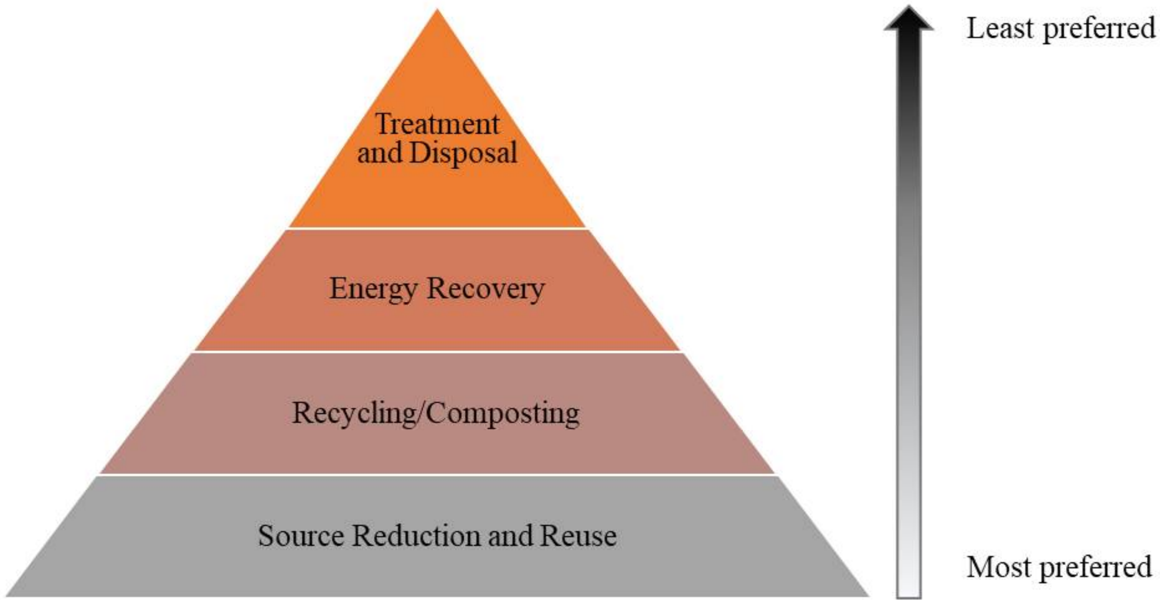

Fig. 1.1 The Solid Waste Management Hierarchy

It is better to reduce the waste at the source of production than managing it at a later stage. The production process is modified in such a way that the quantity, as well as ill-effect on the surrounding, be minimized. It can also be called as waste prevention, as by making favorable changes in the design and manufacturing process, the quantity and adverse effect on the environment, till the end of product life, can be prevented. In the industrial operation adoption of innovative methods, upgrading of equipment is helpful to reduce the volume of waste production, lower the associated risk, toxic nature, and the cost of management. For example, mining operations can be improved by adopting advanced technology to handle mineral ore, acid mine drainage so that tailing wastes can be minimized.

The recycling is adopted after all the attempt has been made to reduce the waste at source. The process consists of segregation of waste material followed by identifying the reusable fraction. Developing a product from recycled waste and encourage people to purchase such a product is also a part of recycling. This practice helps to preserve natural resources exploited for the procurement of raw materials, reduction in the waste generation along with energy requirement, and corresponding pollutions. In a long run scenario valorization of waste will also economically beneficial for the industries. For example, fly ash (FA), one of the common wastes generated from thermal power plants, has been extensively utilized at specific percentages in cement manufacturing industries that increases the strength of final mortar/concrete and reduces the production cost.

Combustion process, the next step of waste management, is a confined and controlled incineration of waste material. Through this process, not only the calorific value of the waste is utilized but also the volume of the waste material reduced significantly before dumping in the landfill. However, the combustible and non-combustible waste must be separated prior to burning. The calorific value of this separated waste also needs to be known, and the suitable mix is required to get the desired temperature.

Treatment and disposal in landfill are the least preferred of all other process and need to be implemented in an integrated way for the complete waste management system. While disposing into landfill, effective performance monitoring and environmental impact assessment operation need to be followed. The landfill operation is majorly depending on the management of leachate and contamination of wastes. To support this, an effective landfill site, require regular inspection, maintenance, and performance evaluation. Generally, non-hazardous waste does not require any treatment. However, they can be treated further to reduce their volume for better efficiency of waste management system with optimal cost. As far as hazardous wastes are concerned, it is essential to characterize them, on the basis of which appropriate techniques (e.g. waste separation, incineration techniques, non-thermal techniques, stabilization, solidification, decontamination, etc.) can be adopted.

1.1.2 Waste management in India

India is shifting towards industrial and services outcome-based country from an agricultural country. It has a heterogeneous climate (mountainous, tropical wet and dry, subtropical) with different seasons (summer, rain, autumn and winter) and diversified geography. About 31.2% (377 million) population in India is living in urban areas (Joshi and Ahmed, 2016). The industrial contribution of waste has been increasing exponentially due to industrial development and progressive increase in living standards. Although central pollution control board (CPCB), New Delhi has set up guidelines for waste management in India, the most challenging problem is to collect it with proper segregation of municipal solid, construction and demolition waste (C&D),

plastic wastes, industrial and commercial waste, and e-waste. Moreover, the management of industrial waste is much tricky in Indian context as the location, industry type, and disposal mode vary significantly. The problem arises due to improper industrial waste management practices and lack of awareness and motivation especially at small and medium scale industries. The unauthorized industries are also one of the major problems in the quantification of waste. However, the industries set up outside the urban areas are disposing almost segregate waste but on an unlined and improperly managed landfill sites. There are many kinds of industrial waste whose significant fraction is putting severe irreversible pollution to the surrounding soil, air, and groundwater.

Globally, the production of electricity itself has become a massive industrial activity, which has been increasing over the years with the rapid urbanization and daily demand. The electricity has become a primary requirement for the survival of human beings. Although there are many methods to generate electricity ranging from a coal-based thermal power plant to nuclear, solar, wind, tidal, and geothermal. However, the major part of it is generated by thermal power plants. Coal performs a significant role as fuel in thermal power plants. Coal-based power plants currently fuel more than 40% of the global electricity though this figure is much higher in many countries (OECD Factbook, 2014).

Moreover, to cope up with the growing energy needs of the developing world, coal is likely to remain a key component among the power generation sources in the foreseeable future, regardless of the climate change policies. However, the combustion of coal for electricity generation also generates vast amounts of FA as a by-product which need to be properly disposed to reduce the magnitude of environmental problems. Fly ash itself is enriched with numerous trace elements and heavy metals (U, Th, Cd, Cr, Pb, Hg, As), most of which are toxic in nature. Throughout the world, about 70% of FA produced from coal power stations is disposed of in landfills and ash ponds.

After China and USA, India is the third biggest coal producer around the globe (Fig. 1.2). In India, about 169.25 million tons of FA is being disposed of from 155 thermal power plants annually (CEAR, 2017). In the past, the FA disposal on landfills and ash ponds were done without proper liners. Moreover, even if liners are used, they lose their effectiveness with time in old landfills and ash ponds, which degrade and pollute the surrounding environment. Additionally, the increasing energy demands leading to increased production of FA by way of increased coal combustion has also led to the exhaustion of these landfills and ash ponds. The excess FA is often dumped in open pits or old mines without proper containment measures. Therefore, the dumped FA gets exposed to the surrounding environment resulting in leaching of heavy metals into deeper soil layers and groundwater, which is a major environmental concern globally.

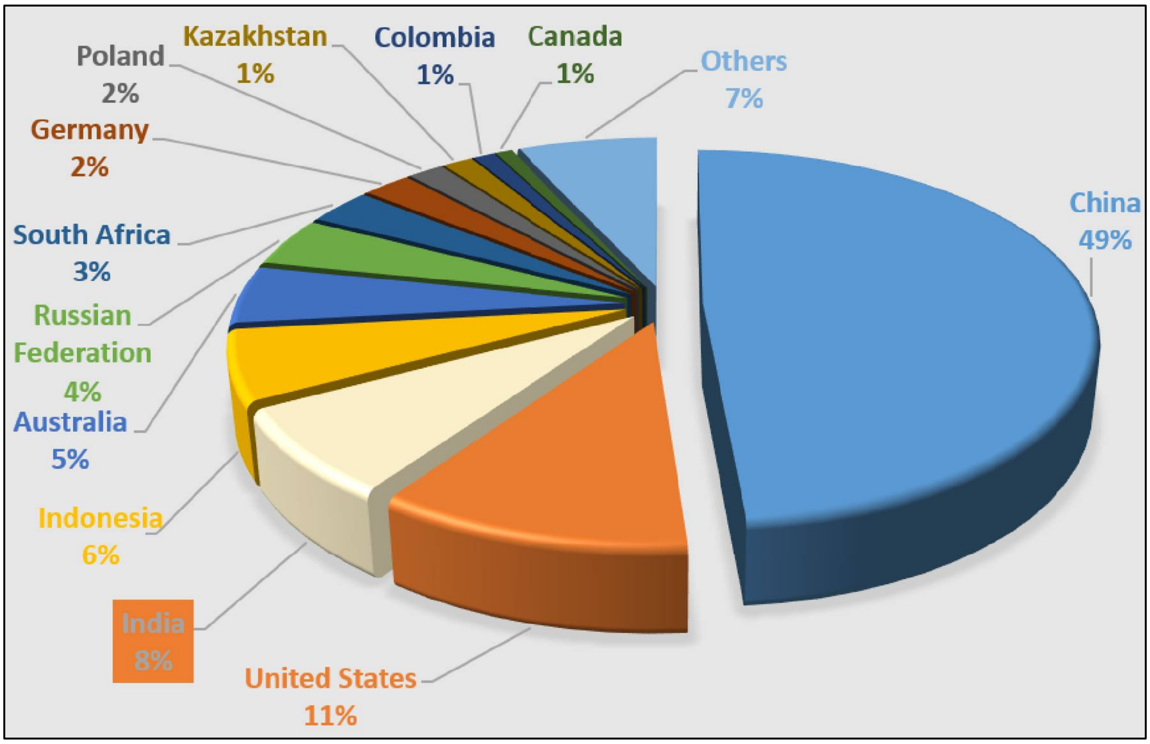

Fig 1.2 Country wise coal production around the globe (web reference, 2019)

In addition to the growing energy needs, today's standard of living also relies on the supply of natural resources. As such, with the increase in industrialization, the mining industry is also growing at a swift pace. However, it has been rightly told by the critics that the mining industry rapes virgin territory and leaves permanent scars and massive footprints in landscapes. The mining industry of India is 4th largest in the world by volume and 8th in terms of revenue generation point (MSPI GOI, 2011). As a consequence of mining, the vast majority of the waste end-product which is left over after separating a small fraction of the concentrate of the sought-after commodity, from the uneconomic fraction of the ore, is known as "Tailings." The composition of tailings is directly dependent on the composition of the parent ore and the process of mineral extraction used on the ore. It may contain trace quantities of metals found in the parent ore, and they may contain substantial amounts of added compounds used in the extraction process as well. Common minerals and elements found in tailings include Arsenic, Cadmium, Barite, Calcite, Fluorite, radioactive materials which are toxic. The physical and chemical characteristics of the tailings vary with the nature of the ore and also with the chemicals added during the processing of the ore. As a result, the disposal of tailings constitutes one of the most significant areas of potential environmental risk.

The seriousness of the threats posed by the heavy metal leaching from both FA and mine tailings by way of their disposal has initiated a series of research initiatives aimed at curbing the problem by prevention and treatment. One such way would be to convert these wastes into an insoluble and harmless form as much as possible (such as hydroxides and sulfide compounds, which have slower leaching rates than the original species) to prevent their re-entry into the environment. They can also be converted to different products which are economical and sustainable.

Environmental as well as economic considerations, play a significant role in the utilization of the waste materials like FA and mine tailings in conjunction, which can solve problems of both wastes simultaneously. Utilization of FA also reduces disposal costs while increasing revenues through the sale of FA. Moreover, FA used in combination with mine waste can reduce greenhouse gas emission by replacing other alkaline materials such as cement/lime, used for solidification to prevent leaching, which generally contributes CO_2 during their production. Also, if these combined materials can further be used successfully for other purposes as in concrete or road pavements, then the overall problem of waste disposal can be reduced considerably. Hence this site-specific study is undertaken to assess the reduction in leaching of various metals or compounds from both these wastes and to evaluate the potential of combined utilization of Khetri copper tailings (CT), and FA for other purposes such that the waste disposal problem is minimized.

1.2 Objectives of the Research

The primary aim of the study is to reduce the adverse impact on the surrounding environment and suggest a sustainable utilization of FA and CT. The objectives of the current study are divided into the following points:

A. To understand the characteristics of fly ash, copper tailings and groundwater.

B. To determine combine leaching effects of FA and CT (by both batch and column leaching experiments) and their potential impact on groundwater nearby disposal sites.
C. To determine the optimum FA and CT ratio for co-placement to effectively immobilize heavy metals.
D. To determine possible sustainable and economically viable utilization of FA and CT in chosen material using analytical and experimental analysis.

In the current research, an attempt has been made to understand leaching behavior of FA and CT, which have been collected from the specified locations, as mentioned in Fig. 1.3. The groundwater samples are taken from nearby villages of the waste sampling locations.

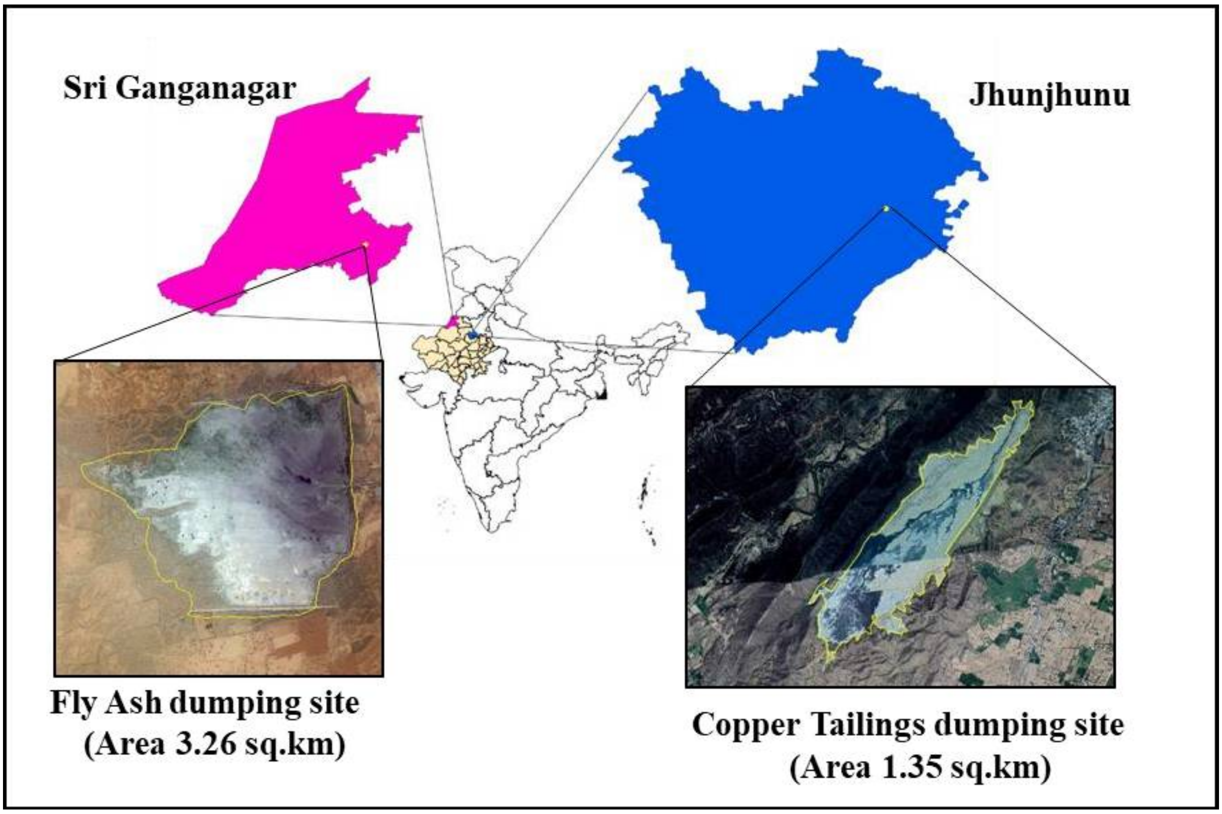

Fig. 1.3 Sampling location of FA and CT

1.3 Scope of the Research Work

The physiochemical analysis of the waste materials is the necessity for understanding their long-term behavior and potential of leaching effects. It primarily depends on the characteristics of parent martial from which the waste material is processed. CT as mining wastes, contributes to the acid mine drainage (AMD) to the environment and pollute the surrounding. FA is also a coal combustion waste polluting the land, air, surface and groundwater. The research work presented in this thesis gives a broader perspective in terms of adverse effect on the environment by unmanaged disposal of both FA and CT. Also, ways to achieve economically feasible and sustainable utilization solutions are suggested under different scenarios. This will not only help in the reduction of the ill-effect on the surroundings but also prevent the valuable land.

1.4 Research Significance and Methodology

Environmental as well as economic considerations, play a major role in the utilization of waste materials like FA and CT. Utilization of FA reduces disposal costs while increasing revenues through the sale of FA. Moreover, FA used in combination with mine wastes can reduce greenhouse gas emission by replacing other alkaline materials such as cement/lime, used for solidification to prevent leaching, which generally contributes CO_2 during their production. Also, if these combined materials can further be used successfully for other purposes as in concrete or road pavements, the overall problem of waste disposal can be reduced considerably. Hence this site-specific study is undertaken to assess the reduction in leaching of various metals or compounds from both these wastes and to evaluate the potential of combined utilization of Khetri Copper mine tailings, and Suratgarh fly ash for other purposes such that the waste disposal problem is minimized. The details of the methodology adopted in the research work is presented in Fig. 1.3.

1.5 Major Outcome of the Research Work

Chapter 1 gives the important aspects of waste management for global as well as Indian context. The cause-effect of FA and CT on the surrounding are presented in this chapter. The comprehensive problem statement, objectives along with scope and organization of the work are also detailed in the chapter.

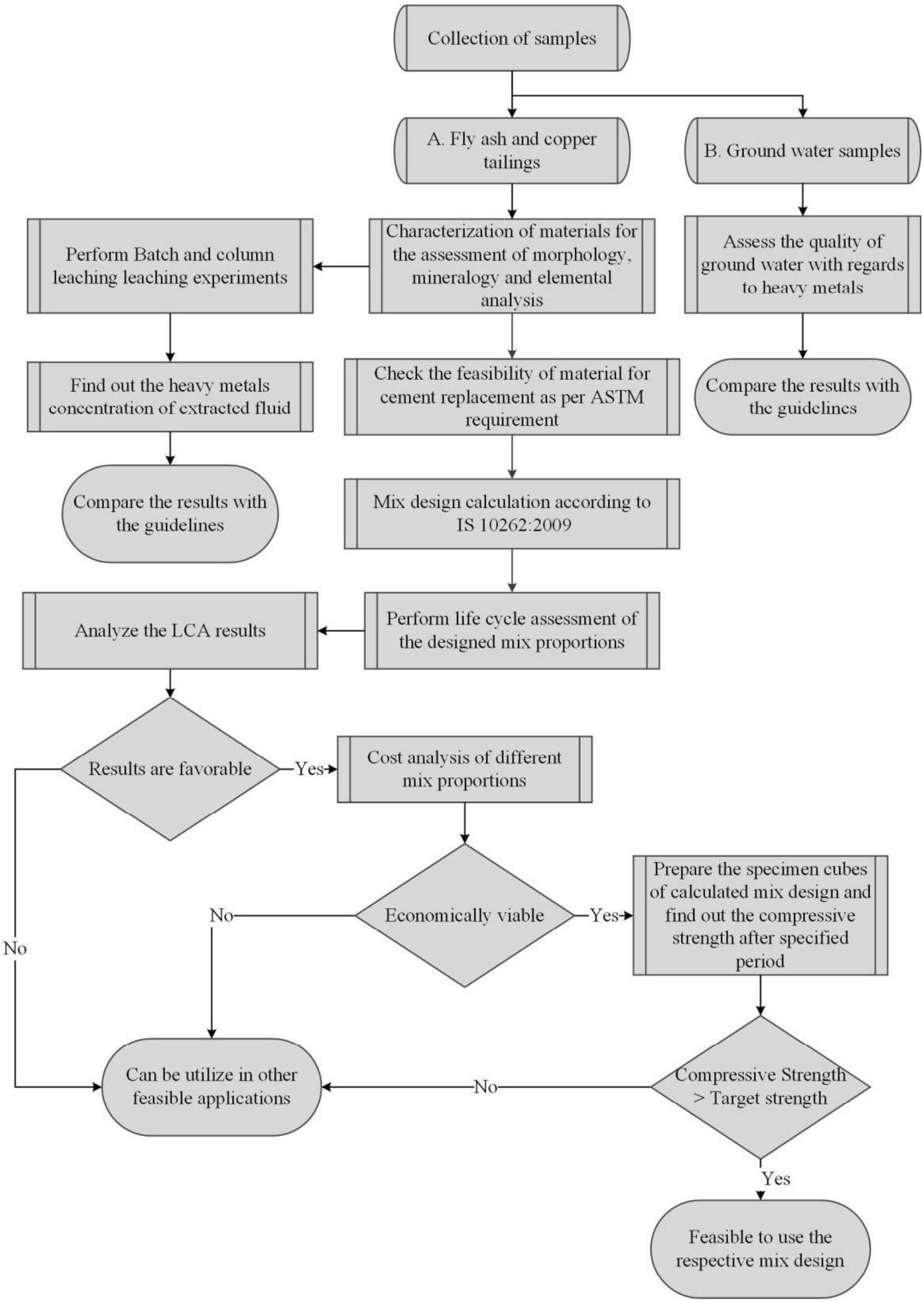

Fig. 1.4 Methodology adopted in the research work

Chapter 2 gives the details of earlier research work and methodologies adopted by various researchers. Initially, comprehensive research work presented in the literature with regard to the potential environmental impact due to FA and CT disposal is summarized. Many successful attempts have been studied to understand the leaching potential of FA and CT. They are also presented in the chapter. Detail of earlier research performed concerning the utilization of FA as an adsorbent, synthesis of zeolite, construction (cement), lightweight building materials, brick manufacturing, road base/subbase, mine backfill, landfill liner, polymer manufacturing, soil amendment, as a mineral resource and waste stabilization are compiled. Some of the studies performed to present possible use of CT in metal recovery, concrete, and brick manufacturing are also presented in this chapter. A summary of the previous researches performed in the field of environmental impact assessment using LCA tool and its utility in the current work are also discussed.

Chapter 3 confined to the characterization of materials. In this chapter initially, a brief detail of the sampling location of the FA, CT, and groundwater are presented. In the next part of this chapter, different technique viz. X-Ray Diffraction (XRD), X-ray fluorescence (XRF), and scanning electron microscopy (SEM) adopted for the characterization of material are summarized along with results of the analysis.

Chapter 4 covers all the aspects related to the leaching involved in the current research work. Brief discussion with regard to leaching studies, their classification are presented in the initial part of the Chapter. Later, the details of experimental set up were presented which was developed in the laboratory for a different combination of extraction of fluid on a different mix of FA and CT. The results of the elemental analysis of all the leachate and groundwater samples and their comparison with the standards are also summarized in this chapter.

Chapter 5 deals with the study, which was performed to understand the environmental impact assessment of the utilization potential of FA and CT in concrete through LCA tool. Initially, details of the LCA were presented, and the necessary steps to be followed in the analysis are summarized. In later part of the chapter, the feasibility of the FA and CT utilization in concrete as a partial replacement of cement is identified through the material characterization results. Then different mix proportions are calculated for a specific target strength along with the control mix. LCA analysis results for all the mix proportion are presented showing the mid-point and endpoint results in the form of different bar charts. Lastly, in-depth cost analysis of the modified concrete mix proportion was also presented with proper findings.

Chapter 6 covers the assessment of the compressive strengths results of different design mix by combinedly replacing cement with FA and CT. The compressive strength after specified time presented in separate bar charted to compare with the target strength and the strength of the control mix.

1.6 Organization of Thesis

An attempt has been made through this thesis to achieve the objectives mentioned above. The thesis is divided into seven chapters. Brief details of the next six chapters are given below:

Chapter 2 presents the literature review related to the research work contributed by different researchers to date related to disposal, effects, and utilization of FA and CT in various applications.

Chapter 3 deals with the material and methods used in the thesis. Details and location of the sampling sites are described along with the results of the characterization of FA and CT to understand different aspects of the material.

Chapter 4 discusses the results of the leaching experiments to identify individual and combined leaching effect of both FA and CT.

Chapter 5 shows the economic and life cycle assessment of the production of concrete using FA and CT as a partial replacement of cement

Chapter 6 details the utilization potential of FA and CT in concrete along with the results showing the effect on the strength.

Chapter 7 deals with the overall summary, conclusions and future scope of the thesis along with the limitations.

The understanding obtained through this research work is believed to be of vital implication in identifying immobilization potential of heavy metals in fly ash and copper tailings and their sustainable utilization for better environment, which is required in current scenario in general and in Indian context specifically.