1.1 Background of the work

1.1.1 Waste generation

The growing population of the whole world leads to rapid urbanization and industrialization for a better standard of living. It creates a few challenges for the environment; one of them is waste generation. Waste is a needless product arising from different human activities like domestic, public, and industrial. It is increased proportionally with the growth of the living standard. Waste is also a rejected material that has no particular uses, so its management is required with greater consideration. Generally, uncollected waste dumped on the side of the streets, drains, and banks of the rivers, and it is contributed to the spread of diseases, flooding along with pollution of air, water resources, and the environment. The definition of waste management varies with the type of waste, but the fundamental concept is always the same, i.e., minimization of the amount of waste to its lowest level.

The wastes are generated from different sources such as agrochemical industries, chemical industries, nuclear power plants, power plants, hospitals, vehicles, etc. Depending upon the toxicity and origin of the waste, they are separated into the subsequent sub-headings (Upadhyaya, 2013):

- **Municipal waste**

  This waste is a mixture of organic and inorganic substances, generated from human activities in public and technical facilities, households, trade, services, administration in communities and cities. It consists of solid and semi-solid substances like vegetables, food, glass, paper, textiles, metals, woods, and cardboards, etc.

- **Industrial waste**

  Industrial waste is retained harmless to very toxic elements or chemicals. This waste is generated from the different phases of production process. It is composed of papers, textiles, glasses, plastics, metals, organic substrate and others.

- **Hazardous waste**

  Hazardous waste arises from numerous sources, including households, industry, and commercial activities. Mostly, this waste is generated from chemical plants like pesticides, medicine, insecticides, biochemical industries, dyes, and paint factories. This waste is very dangerous for living beings and surroundings because it contents toxic and heavy elements.

- **Construction and demolition waste**

  This waste is produced from the destruction and construction of commercial enterprises. This waste includes glasses, brick, steel, nails, plastic pipes, rubber, electrical wiring, and wood. This type is bulky, heavy, and high density, and it does not generate any chemical or biochemical pollution.

- **Mining waste**

  During mining and processing of the coal, different metal ores are generated huge quantities of solid waste. This type of waste includes waste rock, sediments from ore dressing, mine heaps, and topsoil. This waste consists of a variety of materials such as lead, sulphides, carbonates, and metal oxides.

- **E-waste**

  E-waste is generated from the electrical and electronic equipments. Mostly, the sources of the wastes are IT, lighting equipment, telecommunication equipment, control and monitoring instruments, etc.

- **Radioactive waste**

  Radioactive waste is generated from the military activities (recovery of spent fuel from submarines, driving ships, weapons testing, and military reactors), the nuclear industry (x-rays, gamma rays, infrared rays, and ultraviolet rays), radiopharmaceuticals and scintillation solutions. This waste is the most harmful to the environment compared to the other wastes. It is capable of affecting a large area in a very short time, and the distractive power is very high compare to any other wastes.

1.1.2 Waste management

The most common and preferable waste management system is 3R hierarchy system, i.e., reduction, reuse, and recycle, which deals with sustainability and eco-friendly. The industrial waste management hierarchy is depicted in Figure 1.1 (Gorilla, 2019). The hierarchy is organised according to the preferable waste management options such as reduction, re-use, recycling, other processes of recovery such as materials and energy from the waste, and final disposal after that monitoring.

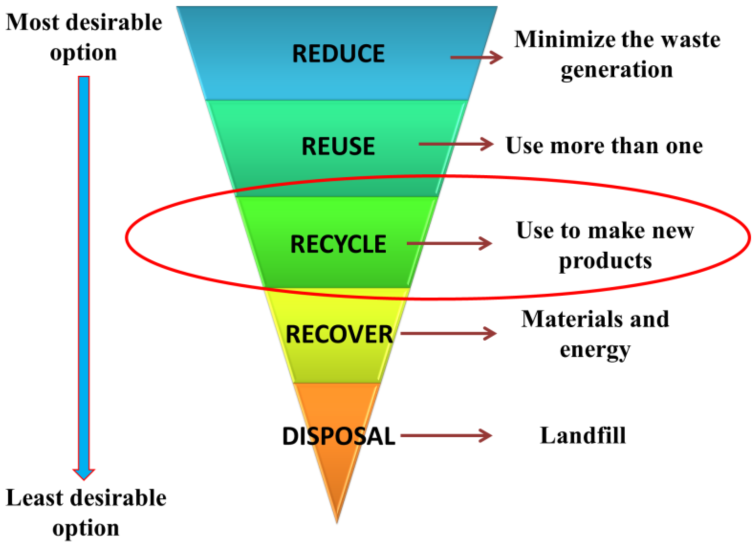

Figure 1.1 Industrial waste management hierarchy.

Reduction in waste generation is the first and important step for waste management. A low waste generation rate means fewer struggles for the management of waste. Municipalities and industries can minimize the waste generation by carefully treating the sources of waste. Reuse is a process of using any products for more than one time to prolong its lifespan. We reuse so many things in our daily life. So, we can reuse the materials or goods to help the disposal problems and waste management costs. The recycling is performed by the reuse of some percentage of residues or wastes from the production as raw materials for making new products or as energy sources. Glass industries are recycled the waste glass as a cullet for the preparation of new glass with virgin raw materials. Fly ash and kiln dust are utilized for the production of cement. Metal scraps like iron and aluminium are completely recycled nowadays for the preparation of respective products. Municipality solid wastes can also be used as an aggregate in the construction sectors. Similarly, ceramic industries are also attempting to recycle different solid wastes as a replacement for natural raw materials.

1.1.3 Ceramic

'Ceramic' is a Greek word, earlier it was expressed as clay-based wares, i.e., 'pottery'. Nowadays, ceramic has more roomy meaning as inorganic, non-metallic, or metalloid solid compounds that are predominantly bonded with a mixed type of bonding (both ionic and covalent bonds). Now, pottery is just a part of the ceramic world. Richerson (2000) has explained the term ceramic as "the most solid materials that aren't metal, plastic, or derived from the plants or animals." Ceramics have some unique characteristics, which are not offered by the metals or other solids, including a high melting point, good chemical inertness, brittleness, high-temperature stability, heat, and electrical insulation ability (Kingery *et al.*, 1976). Therefore, ceramics have a huge range of applications in the modern society, and expecting the demand for ceramics will be more strongly increased in the near future. In a very broad term, ceramics are used in modern day-to-day life as bricks, glass, tiles, tablewares, sanitarywares, space, cars, abrasives, biomedical (artificial bones and teeth), and electrical or electronic devices applications (Ceramics and Glass in Everyday Life, 2019). All these ceramic products are mostly manufactured by the consumption of the massive amount of raw materials from the nature. The oldest and the most used raw material of the ceramic is natural clay. Generally, the pottery is made by the conjunction of raw materials like clay, silica, and a certain amount of alkali-bearing materials (feldspar) as fluxes. Figure 1.2 shows a diagram that illustrates the standard compositions of common tri-axial ceramic products (Romero and Pérez, 2015). The refractory industries are used as the source of alumina, magnesite, chrome, dolomite, zircon, quartz, and little or no clay as raw materials according to the specialized refractory. Table 1.1 represents the mostly used raw materials with their sources for making whitewares, refractories, and glasses. Consequently, a wide variety of synthetic ceramic materials have also been developed for different advanced fields like electrical or electronics, nuclear power, and structural engineering. For example: various nitrides or carbides for heating elements; abrasives and engineering construction materials; zirconia, mullite, spinel, forsterite, beryllia, and thoria for advanced refractory; rutile for ferroelectric materials and uranium oxide as a nuclear fuel element application (William, 1978; Worrall, 1986; Kang *et al*., 2011). All the sources of ceramic raw materials are natural. Therefore, the huge intakes of natural ingredients by the ceramic industries create a shortage of these natural resources and affect the eco-system. Therefore, researchers are trying to find a substitute for the natural ingredients for the ceramic industries.

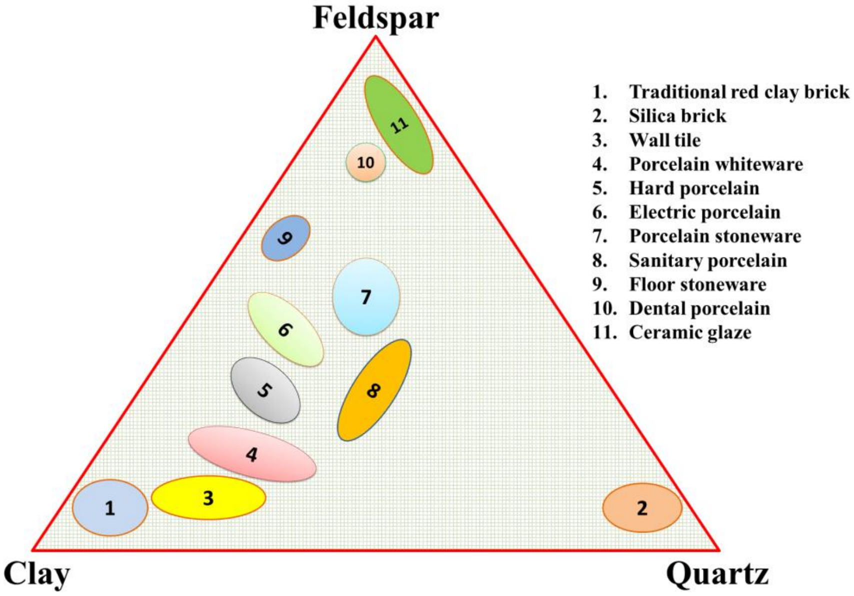

Figure 1.2 Tri-axial (feldspar-quartz-clay) compositions of common ceramic products [Romero and Pérez, 2015].

Table 1.1 Common ceramic raw materials and their sources.

Products	Raw material	Source
Whiteware	Clay	Different natural clays like China clay, ball clay, fireclay
	Silica	Quartzite, ganister, silica sand, flint, chalcedony
	Feldspar	Orthoclase, albite, anorthite
Refractory	Silica	Quartzite, ganister, silica sand, flint, chalcedony
	Alumina	Bauxite, diaspore
	Magnesia	Magnesite, dolomite, Sea water
	Chromium	Chromite
	Zirconia	Zircon

	Silica	Quartzite, ganister, silica sand
Glass	Calcium oxide	Limestone
	Sodium oxide	Albite, soda ash

1.2 Statement of the problem and rationale

The growing population of the whole world demands an expansion of industrial production to fulfill the requirements of the populace. It creates two kinds of problems on the ecosystem, i.e., the disappearance of the natural resources and generating excessive wastes. The unmanaged waste causes environmental pollution as well as disposal problems, harms both humans and animals, and can even disturb the economic growth of a region. From the perspectives of the economies, energy needs, and the environments of developing as well as a developed nation, one way to minimize these problems is to recycle these industrial by-products or wastes as main streams of industrial production. In accordance with this realization, every manufacturing sector looks to raise its profit by utilizing the wastes in place of virgin resources for the production of products (Chaaban, 2001). In this aspect, the ceramic industries also have good environments for the utilization of the by-products or wastes in their productions. Therefore, researchers have been performed in the last two decades to accomplish this objective for the ceramic industries. Thus, some wastes, e.g., rice husk ash (RHA) (Liu *et al*. 2016; Prasara-A and Gheewala, 2017; Shen, 2017), fly ash (FA) (Luo *et al*., 2017; 2018a; 2018b; Han *et al*., 2018), blast furnace slag (BFS) (Ozturk and Gultekin, 2015), waste marble powder (Sutcu *et al*., 2015), oil production waste (Bories *et al*., 2015), paper-processing residues (Sutcu and Akkurt, 2009), polished tile waste (Ke *et al*., 2016), bottom ash (Carrasco-Hurtado *et al*., 2014), water treatment sludge (Geraldo *et al*., 2017), petroleum waste (Pinheiro *et al*., 2013; Das *et al*., 2018), and glass waste (Teixeira *et al*., 2017) have been identified as potential ingredients to use in making of different ceramics.

1.3 Theme of the work

The theme of the present study is to synthesize eco-efficient and sustainable ceramics by utilizing the different wastes, mainly RHA, eggshell (ES), seashell, and FA. In most cases, the lengthy, complicate, and expensive processes are required for the fabrication of ceramics through the utilizing of wastes. The preparation of waste-derived ceramics through ecological and economical routes is challenging. We have investigated multiple facile and sustainable routes for the preparation of ceramics with maximum wastes incorporation in the compositions. These can be attended by the changing of different process parameters like a waste to natural raw material ratio, firing temperature, compaction pressure, treatment of wastes for purity and particle size, and selection of suitable wastes for appropriate products.

In this investigation, waste RHA is used mainly as a silica source, FA for alumina-silicate source, ES, and seashell for calcium oxide source. Additionally, the river silt into the tile composition; refractory grog into the insulation refractory brick composition is also added for increasing the amount of the waste. The specific objectives of the study are as follows:

- To synthesize high purity nano-silica and silica sol from waste RHA and use to prepare silica foam, mullite foam, and castable refractory.
- To synthesize low cost, synthetic wollastonite from waste RHA and ES, and study the dielectric and fluxing properties.
- To fabricate ceramic board using RHA, RH, FA, and seashell for constriction purposes.
- To prepare fired insulation refractory brick using RHA, FA, refractory grog, and rice husk.

1.4 Scope and limitation of this study

1.4.1 Scope

This study will provide information regarding wastes, which can be capable of developing ceramics. This work will deliver a deep knowledge about the processes that are involved in making sustainable ceramics by utilizing wastes. It will also discuss about the techniques behind the recycling system, the influencing parameters, and the type of driving factors for the development of ceramics by utilizing wastes. The study will increase an awareness of recycling and highlighting the impotence of the different wastes, which can be enhanced the initiatives for addressing it. Moreover, it will be predictable that the outcome of this work will enable about the commercialization of wastes derived ceramics that will benefit ceramic industries and societies from the waste management.

1.4.2 Limitation

Some conditioning features, like the compatibility between natural raw materials and wastes, the characteristics of the final product, continuous availability, transport costs, constant chemical compositions, and the pre-treatments processes are limited to the utilization of wastes in the production of ceramics. The origin of parent ingredients greatly influences the chemical composition and characteristics of the wastes. The variations of the waste properties are forced to change the process parameters for making particular ceramics.

1.5 Organization of the thesis

To meet the objectives of this study, the thesis is organized into eight chapters:

Chapter-1 gives a brief introduction about the research background, the importance of the wastes, and the organization of the thesis.

Chapter-2 provides an up-to-date overview of the recent waste-derived ceramics, including refractories, glasses, whitewares, some oxide and non-oxide ceramics with the correlation of waste incorporation limits, manufacturing routes, and properties of the ceramics. This chapter also supports to understand the aims and objectives of the present work.

Chapter-3 explains a detailed description of wastes and other materials which are used as raw materials for the preparation of ceramics. Numerous characterization techniques, which have been used to analyze the physico-mechanical and other properties of the ceramics, have also been discussed.

Chapter-4 describes the extracted methods of nano-silica and silica sol from waste RHA. It also tells about the preparation methods of silica and in-situ mullite foam without the addition of any additives or foaming agents and investigation of their physico-mechanical properties.

Chapter-5 explores a novel approach to investigate the feasibility of using RHA derived silica sol as a binder system for high alumina refractory castable and investigates the physico-mechanical and corrosion behavior with the BFS.

Chapter-6 conducts to fabricate synthetic wollastonite using 100% abandoned ingredients, i.e., eggshell and RHA. The investigation about physico-mechanical and dielectric properties of waste-derived wollastonite is also explained.

Chapter-7 describes the feasibility of using river silt and wastes derived wollastonite as an alternative of quartz and feldspar, respectively, for the manufacturing of ceramic tiles and investigate their important properties.

Chapter-8 deals with a facile preparation process of the ceramic board using FA, seashell, and RHA. The physico-mechanical, effect of humidity on the mechanical property and thermal behavior are also briefly discussed.

Chapter-9 provides a new route to utilize the waste FA, refractory grog, and RHA as raw materials for the preparation of insulation refractory.

Chapter-10 includes all the remarkable findings from this investigation and gives some proposals for further studies.

All the references have been listed after the end of the chapter-10. Moreover, a list of publications, including journal articles, conference presentations, and patents related to the present study, has been illustrated in the end.